Evaluation of thermal comfort by a Dummy Representing Suit for Simulation of huMAN heatloss (DRESSMAN)

ABSTRACT

DRESSMAN, a new type of thermal manikin is presented. DRESSMAN designates a novel dummy for climate measurements that allows predicting the human thermal comfort experienced inside rooms (buildings, vehicles, aircraft, railway compartments etc) on the basis of indoor climate measurements. It consists of an overall – deliverable in different sizes, which can be worn by a person or a manikin – on which up to 32 heated sensors can be fixed everywhere by velcrose fastening. The heated sensors are matchbox-sized „artificial skins“. These measure the Resultant Surface Temperatures (RST) resulting out of a constant heat flux and the thermal conditions. The local RST is linearly correlated to the local equivalent temperature and the human thermal sensation. The data transfer of the sensors to the PC is wireless. DRESSMAN combines advantages of heated dummies (geometry) and of smaller sensors (small response time, local thermal conditions). Measurement results can be listed in tabular form and be represented by way of color gradations in a virtual 3D human model, as well. Optionally, visualization may be rendered while measuring or subsequently. Due to its very quick response, DRESSMAN is particularly suited for nonstationary processes.

1. INTRODUCTION

In the past human thermal comfort was either measured by small sensors or by “full size” thermal manikins. The disadvantages of those methods: not taking into account the geometry of the real human body in the first case (e.g. relevant for draft-measurements) – and not analyzing local effects (relevant for draft-measurements, too) are avoided when combining both methods – realized by DRESSMAN.

2. DESCRIPTION OF THE MEASUREMENT EQUIPMENT

DRESSMAN consists of an overall suit, to which up to 32 heated sensors may be attached. These sensors, which are called RST-meters (=Resultant Surface Temperature), simulate the human skin by means of a constant heat flux. The temperatures resultant at the surface of the RST-meters are a consequence of the thermal ambient conditions that usually act differently on different parts of the body.

The RST-meters are constantly heated by resistors on a surface of about 1 cm². Edge heater units and counter heating units ensure a defined heat flux of e.g. 85 W/m² (adjustable) which is directed E. Mayer is head of the division Indoor Climate at the Fraunhofer-Institute for Building Physics, Holzkirchen, Germany; R. Schwab is head of the group Thermal Comfort at the Fraunhofer-Institute for Building Physics, Holzkirchen, Germany. Director of the Institute: Prof. Dr. Dr. h.c. mult. Dr. E.h. mult. Karl Gertis (93x68)
towards the front side. The actual quantity being measured is the Resultant Surface Temperature (RST) which results on the measurement surface, depending on the climatic boundary conditions, measured by means of NTC resistors. Actually, the sensor simulates the human skin with regard to the dry heat interchange with the environment, and RST represents a climate summation quantity. Then follows the wireless transmission of this RST-value to a receiving station that is connected to a notebook, as wireless transmission allows for a maximum possible freedom of movement and simple applications.

The local RST-value has a linear correlation with the local equivalent temperature and the human thermal sensation at those parts of the body that were measured. DRESSMAN combines the advantages offered by heated manikins (geometry) and by small sensors (quick response times, detection of thermal conditions that are locally distinctly different).

Since the entire overall suit consists of the "fleece part" of a Velcro fastener and the RST-meters have an "adhesive part" on their backside, these may be attached to any spot and can be easily removed again. In this way, DRESSMAN is a "suit" that simulates a human being's heat emission. This suit can be worn by a human individual (e.g. a car driver, a pilot, etc.) and a test dummy, as well. DRESSMAN is suited for applications inside buildings and inside means of transport in order to measure the thermal comfort conditions that are liable to develop therein.

Figures 2 and 3 illustrate how DRESSMAN is applied to a person sitting inside a passenger car and to a life-size dummy placed inside an airplane cabin. The RST-meters can be attached to any points of the overall suit.

**FIGURE 2.**

DRESSMAN on an individual seated inside a car, consisting of an overall suit provided with RST-meters. At the end of the rods that look like antennas, there are air temperature sensors.

**FIGURE 3.**

DRESSMAN applied to a dummy placed inside an airplane cabin.
3. PHYSIOLOGICAL AND PHYSICAL BACKGROUND

Physiologists have proved that man uses thermoreceptors to feel thermal comfort or discomfort, i.e. receptors that will only react to temperature and changes in temperature, but not to heat flow (Benzinger 1979). In simple words, the sensation of thermal discomfort means that an individual will feel "too cold" if his or her skin temperature drops below a particular threshold value. As a rule, this will be a consequence of local cooling (mostly beginning at the lower extremities, e.g. cold feet), and in a special form by draught. In this case, cold receptors in the skin will react. A sensation of "too warm" is felt if the human subject is exposed to ambient conditions that will eventually raise the blood temperature in such a way that thermoreceptors located in the brain stem region will respond and trigger e.g. perspiration.

These physiological principles lead to physical consequences that provide the basis for the development of DRESSMAN. Basically, human heat loss in thermally comfortable situations is influenced by convection and thermal radiation and may be formulated in a simplified manner (heat conduction and perspiration are treated as negligible quantities) by means of the following heat balance equation, where the sensor's density of heat flow rate is set to 85 W/m²:

\[
85 \text{ W/m}^2 = \alpha_K (RST - t_L) + C \cdot \left[ \frac{(RST + 273,2)}{100} \right]^4 - \left[ \frac{(t_{HR} + 273,2)}{100} \right]^4 \text{ W/m}^2 \tag{1}
\]

where

- \( \alpha_K \) heat transfer by convection [W/m²K]
- \( RST \) resultant surface temperature of the body that has been heated with 85 W/m² [°C]
- \( t_L \) air temperature [°C]
- \( C \) \( \varepsilon_{RST} \cdot \varepsilon_{UF} \cdot C_S = \) radiation coefficient = 4.9 W/m²K⁴ (measured for typical, non-reflecting surfaces)
- \( \varepsilon_{RST} \) emissivity of the RST-meter, here 0.9
- \( \varepsilon_{UF} \) emissivity of the semi-infinite space, with which the RST-meter is in a radiation exchange
- \( C_S \) radiation coefficient of the black body = 5.67 W/m²K⁴
- \( t_{HR} \) mean radiation temperature of the semi-infinite space

The local thermal sensation can be determined from the RST-value by way of the equivalent temperature (which may be derived from this value) or by way of correlating interview responses. A typical correlation is illustrated in Fig. 4. The tests were performed in a simulated motor-vehicle passenger cell under varied summer conditions; the test subjects were dressed in summer clothing and operated a driving simulator.
4. DATA PROCESSING AND VISUALIZATION OF RESULTS

Communication with the sensors is wireless; it is effected via a transmitter that is connected to the PC on which three programs are running simultaneously, namely

- DRESSMAN basic software
- DIAdem®
- DIAdem®-INSIGHT

to which the data are transferred online.

**DRESSMAN basic software**

This program controls sensor communication processes. Measured data will be stored as ASCII-files and as DIAdem®-files. In parallel, data will be transferred via the DDE-interface to DIAdem®. For each one of the up to 32 sensors, about every 30 seconds (cycle time for 32 sensors) the following quantities are being supplied online:

RST-values
equivalent temperature values
air temperature data
PMV-values according to ISO 7730 (Predicted Mean Vote comfort index)
LMV-values (Local Mean Vote; by correlation with interview results, e.g. as in (Schwab 1994))

These values are listed in tabular form and updated at each sensor call, corresponding to the cycle time. On request, a graphical representation of the time profile is possible. Additionally, the sensors may be attached to a human contour in a 2D-graphic and the current measurement data can be displayed numerically or as a sensor color.

Figure 5 shows a typical screen shot of the presentation of results as rendered by the basic software.
In addition to displaying the tabular representation, the measured data can also be visualized in a 3D-representation as graded colors on a virtual dummy, simply by calling this feature on a button. This is achieved through the DIAdem® and DIAdem®-INSIGHT programs.

DIAdem®

While measuring, the current data are transferred to DIAdem® via the DDE-interface. The necessary steps for transferring data to DIAdem®-INSIGHT via OLE are determined in the DIAdem®-DAC part; when starting DIAdem®, the user can choose by means of automatic sequences which one of the above parameters he or she wants to be visualized in color on a 3D-dummy in INSIGHT. A typical circuit scheme is shown in Figure 6.

DIAdem®-INSIGHT

According to the user's choice, a graded-color online-visualization of the above-mentioned parameters is rendered in a virtual 3D-model by DIAdem®-INSIGHT. The measuring channels (sensors) are attributed to the specified parts of the body in accordance with the positions of the sensors that were attached to DRESSMAN. Color grades of those parts of the body, which are not directly involved in the measurement, will be interpolated. Figure 7 shows an exemplary curve of the PMV comfort index, where the color gradation between blue and red corresponds to the range of sensations from cold to hot.
The user is also free to choose a finer graduation of the colors. The visualization is updated with each cycle of measurement, so that transient processes can be recognized immediately in the 3D color representation. While being visualized, the model can be rotated or zoomed in order to focus on parts of the body that are of special interest. Besides visualizing the current values, it is also possible to compare these data to a previous measurement in a similar representation; the exact point in time of the prior measurement may be determined (and altered) on a time scale. Figure 8 shows an example for this option.

5. CONCLUSIONS

The presented new type of thermal manikin “DRESSMAN”, combining the advantages of smell sensors (high solution) and “full size” equipments (geometry-effects) offers chances for a more precise evaluation of thermal comfort than in the past. Its progressive data processing visualizes even inhomoge-
nious and transient thermal conditions of rooms / vehicles in a realistic way. Therefore, DRESSMAN could be a valuable tool for validating CFD-programs in the future.

6. REFERENCES
