ADVANCES IN SENSORS: REVIEWS 8

Sergey Y. Yurish

Editor

Sensors, Measurements and Networks

EXCERPT: Chapter 6
„Measurement of Microclimate as a Comfort Indicator“

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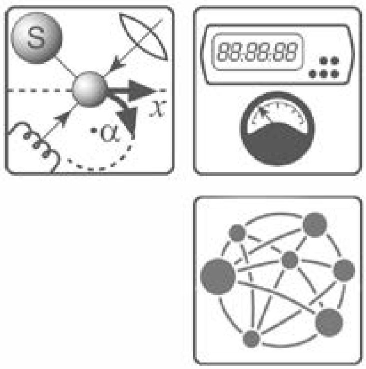

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As Editor I would like to express my undying gratitude to all authors, editorial staff, reviewers and others who actively participated in this book. We want also to express our gratitude to all their families, friends and colleagues for their help and understanding.

Contents

Preface

It is my great pleasure to present the 8th volume from our popular Book Series 'Advances in Sensors' started by the IFSA Publishing in 2012. This Book Series was accepted by all sensor community with a great enthusiasm.

According to *Next Move Strategy Consulting*, the global sensor market is projected to more than double in size between 2019 and 2030. While the market was sized at some 163.84 billion U.S. dollars in 2019, it is expected to reach the size of around 426.2 billion U.S. dollars in 2030. Emerging trends, which have a direct impact on the dynamics of the industry, include development of new product technologies, increasing usage of sensors in various applications, and advances in gas sensor materials and manufacturing.

Since the Vol. 4 of this book series it is published as an Open Access Book in order to significantly increase the reach and impact of this volume, which also published in two formats: electronic (pdf) with full-color illustrations and print (paperback).

The 8th volume entitled 'Sensors, Measurements and Networks' contains twelve chapters with the descriptions of latest advances in sensor related area written by 33 authors from academia and industry from 11 countries: Belgium, China, Czech Republic, Germany, México, Poland, Portugal, Russia, Senegal, Serbia, and the USA.

Like the first seven volumes of this Book Series, the 8th volume also has been organized by topics of high interest. In order to offer a fast and easy reading of each topic, every chapter in this book is independent and self-contained. All chapters have the same structure: first an introduction to specific topic under study; second particular field description including sensing or/and measuring applications. Each of chapter is ending by well selected list of references with books, journals, conference proceedings and web sites.

This book ensures that our readers will stay at the cutting edge of the field and get the right and effective start point and road map for the further researches and developments. By this way, they will be able to save more time for productive research activity and eliminate routine work.

Coverage includes current developments in physical sensors, chemical sensors, measurements and sensor networks. With this unique combination of information in each volume, the Advances in Sensors book Series will be of value for scientists and engineers in industry and at universities, to sensors developers, distributors, and users.

I hope that readers enjoy this book and that can be a valuable tool for those who involved in research and development of various physical sensors, chemical sensors, measuring systems and sensor networks.

I shall gratefully receive any advices, comments, suggestions and notes from readers to make the next volumes of Advances in Sensors: Reviews book Series very interesting and useful.

Dr. Sergey Y. Yurish

Editor
IFSA Publishing *Barcelona, Spain*

Chapter 6
Measurement of Microclimate as a Comfort Indicator

Bernhard Kurz and Christoph Russ

6.1. Introduction

The requirements which are directed to modern apparel like work wear, protective wear, business and fashion wear, as well as to high quality seating or sleep systems, have changed fundamentally in the last decades. Today, apparel systems are expected to be multifunctional, e.g. protection against chemical, mechanical or thermal effects, but also skin-sensory or haptic aspects as well as odor, hygiene and cleaning requirements or biomechanical specifications about fit (see Fig. 6.1).

In addition to the above functions comfort aspects can be roughly divided into the areas of biomechanical and climatic comfort and amend the portfolio of requirements. It must be considered that both these comfort aspects interact and influence each other´s physiological consequences. Poor shoe fit, for example, may increase the biomechanical risk for skin irritations. But in combination with a warm/humid shoe microclimate the risk of comfort loss may even accelerate the process because the mechanical properties of the skin get adversely affected (maceration). It is also known that in the initial phase of using apparel components or seating and sleep systems, at first the biomechanical conditions determine the wearing comfort, better their discomfort, and only after some time the climatic factors gain awareness and sometimes even take over the dominant role. Since comfort may ultimately be determined by no unpleasant sensation, any individual source for discomfort must have a significant influence on the overall perception (see Fig. 6.2). Thus, comfort has a direct impact on physical and mental performance, relaxation, and wellbeing.

In addition to ergonomic and skin-sensatory aspects, such as sweat-induced adhesion or moisture stains, climatic comfort plays a central role, since the global human

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thermophysiological requirement is only met by an even heat balance. At the same time, the heat transport, breathability and moisture management of the garments ensure a pleasant local microclimate at the human/textile interface.

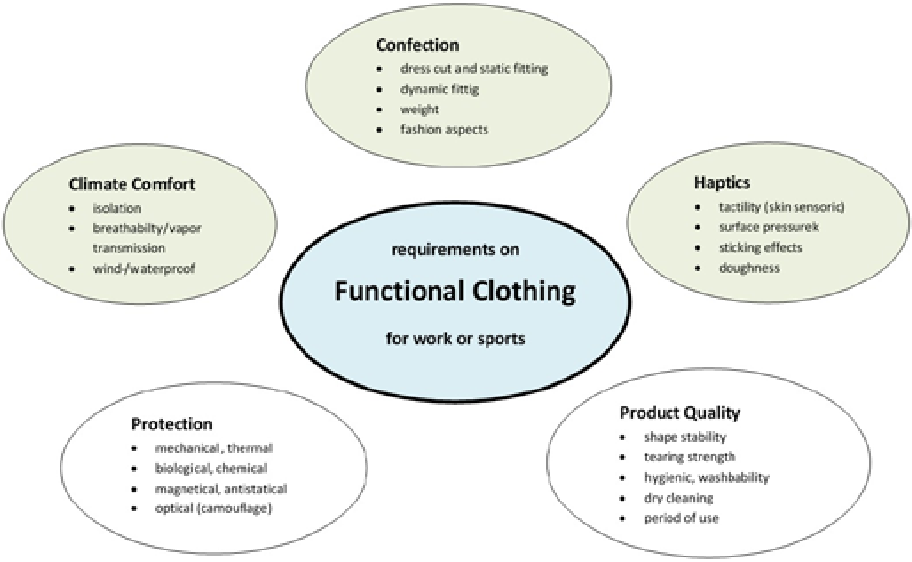

Fig. 6.1. Ergonomical requirements on clothing, green areas with comfort relation.

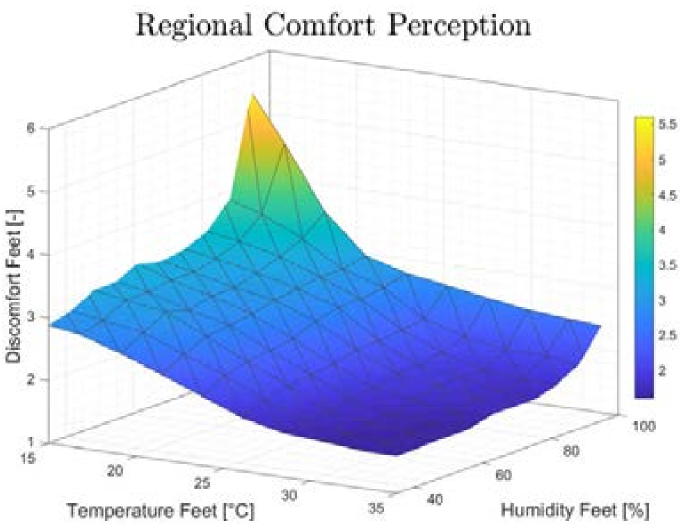

Fig. 6.2. Local discomfort perception in the feet region at various microclimates in the shoe.

Existing testing standards dealing with climatic functions were developed to focus on extreme situations, i.e., protection against rain from the outside but maximum vapor flow rate from the inside. With the successful rise of the outdoor or sportswear industries in the last decades the aim became to determine minimum and maximum heat transfer and vapor transfer rates.

From a climatic comfort point of view, however, extremes such as humidity saturation at the skin/textile interface may happen less than 10% of the using time in everyday life and else must be viewed as unrealistic and certainly unpleasant. This means 90 % of the wearing time are not directly considered and still open for investigation and proof of concept. This requires not only realistic simulation testing to obtain key figures, but also indicators that are comprehensible and meaningful to consumers, for example in the form of combined climate measures such as the Heat Index [6].

In the construction, design, and assessment of climaphysiological functions of apparel or body support systems, and incidentally also for actuator and operating handles, a multi-stage analysis process is consequently indicated by:

- Determination of (bio-)physical parameters for the evaluation of thermoregulatory properties (even heat balance);
- Quantification of the comfort-determining microclimate as a (human-) physiological criterion by standardized testing methodology;
- Use of validated predictive models for comfort prognosis;
- Selected, supplementary validation through tests with probands.

According to numerous studies from a wide range of private and public research institutions [1, 3, 5, 12, 15, 19, 24], the microclimate next to the skin represents the decisive, multidimensional indicator to assess the thermoregulatory function and the climatic and ergonomic wearing comfort. Thus, it must be determined as realistic as possible and requires suitable sensor technology as well as a reproducible and standardized heat and moisture source, without subjective influences from a human subject-based test procedure. The following explanations intend to provide scientific, economical, and practicable approaches.

6.2. Microclimate

To define climate comfort in particular the physiological requirements of the thermoregulation as well as the individual sensations must be analyzed. When humans are asked whether they prefer warm or cool respectively dry or humid climate, the answers indicate a clear preference for dry. Warm or cool remains to be evenly distributed. This is although humans do not have any moisture receptors. Hence, the concept of warm or cold sensation is not only a matter of temperature but must be a combination of heat and humidity developments. This concludes that climate comfort is a matter of “dry” in the first place, warm or cold only ranks second.

To understand the central role of microclimate on the comfort perception, a look at the human thermophysiology can help. Its goal is the production of heat to stabilize the core temperature at about 37 °C. According to any thermal or physical load the heat production will vary. In case of too much heat the necessity of discharge will increase (e.g., sweating), otherwise the heat loss is decreased and additional heat production (e.g., trembling) will start. Heat loss is physiologically controlled by a change of blood circulation within the skin tissue and, in particular the heat increase, also through the evaporation of sweat. In both cases the apparel plays the central role because the heat discharge through the skin reaches about 90 % and just 10 % by breathing [9, 16, 21]. In cold environs apparel must support isolation to avoid too much heat loss. In warm environs the heat and mainly the humidity transmission must be enabled, regarding an evaporation fraction of about 70 % when temperature rises over 30 °C. Both heat transmission mechanisms will determine the temperature and humidity in the microclimate in the layer between skin and textile.

An applied rating method for global thermal comfort which can be found in various scientific literature [5, 8, 11] are the widely accepted ranges of skin temperature for non-extreme ambient climate conditions, limited wind speed and radiation, e.g., specified by the effective temperature [7] as well as energy consumptions below the continuous work capacity (approx. 250 W) which are defined as:

- Optimal range: 31,5 °C – 35,5 °C;
- Transition towards warm: 35,5 °C – 37 °C;
- Transition towards cold: 29 °C – 31,5 °C;
- Comfort threshold warm: above 37 °C (37.5 °C);
- Comfort threshold cold: below 29 °C.

Confirmed by many trials with human occupants on seats, in beds, and with diverse apparel products the human thermoregulation behavior measured as the microclimate close to the skin can be separated into three phases (see Fig. 6.3):

Phase 1: Thermal neutrality, characterized by:

- Low temperature changes with up to +/- 1 °C within the comfort range 31,5 °C – 35,5 °C;
- The heat balance is even, sweating as active body own method to influence the heat only happens in little doses (fine tuning);
- Dynamic regulating activity of low sensitive perspiration with slightly upward and downward developing absolute humidity levels (up to 25 g/kg) occur, which over time do not accumulate in the human/textile interface.

Phase 2: Tendency to feel cold, characterized by:

- Decrease of the skin temperature below the comfort zone; risk of a reduction of the body core temperature;

- Demand for heat supply increases; sensitive (active) sweating shuts down; humidity gradients decrease or remain stable;
- Lowest sweat emission, only insensitive sweating with very little absolute humidity and low to zero dynamic.

Phase 3: Tendency to overheat and sweat, characterized by:

- Increasing skin temperature over the comfort level; increasing tendency of the body core temperature;
- The demand for heat release increases; growing sweat activity with higher upward trends of humidity levels (over 25 g/kg);
- In the measurable view a medium to high accumulating absolute humidity in textile layers can be seen.

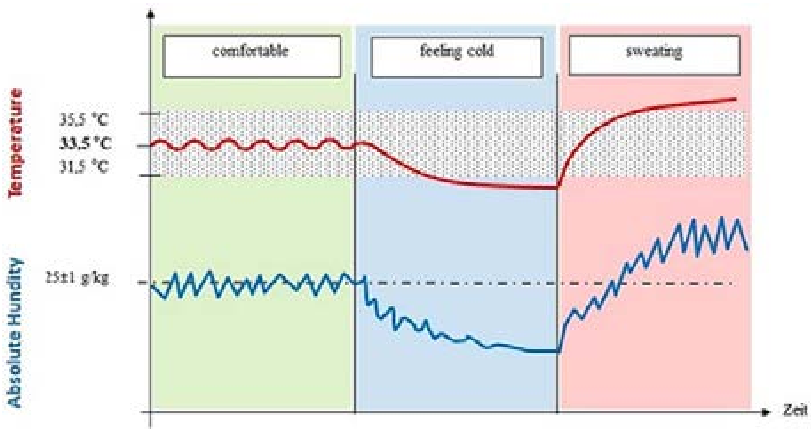

Fig. 6.3. Characteristics of thermoregulative phases.

Thus, the decisive conclusion for a measured assessment of climate comfort is to focus on the directly developing microclimate at the human/textile interface providing kind of a blueprint of the thermoregulation processes [12]. Combined with individual climate sensations the perceived comfort can be derived with high validity (see Fig. 6.4).

The investigation on regional comfort temperatures at diverse body parts can be found with Arens and Zang [2]. The common way to conduct such climate data in most cases is that they are recorded close to the skin or with one apparel interlayer and at different ambient temperatures as well as microclimate sensors.

Under these circumstances it must be realized that wearing different apparel systems under use of different measuring devices complicates the choice of suitable and comparable measurement positions. Moreover, the thermoregulating homoiothermia makes for the skin temperature to scarcely vary, which requires a precise and reproducible temperature resp. temperature distribution measurement, e.g., as mean skin temperature acc. to Ramanathan. Practical approaches to solve these challenges are an area related detection of the temperature and humidity allocation with cluster formation, and correlation analysis between perception and selected measurement sectors. Given a predominantly direct contact of a human and a test object, e.g., seat, laying or shoe systems, and only one defined interlayer of apparel the evaluation of thermal comfort can be obtained from the temperature values in the interface apparel to test object, e.g., directly on the seat or cushion surface [14, 17].

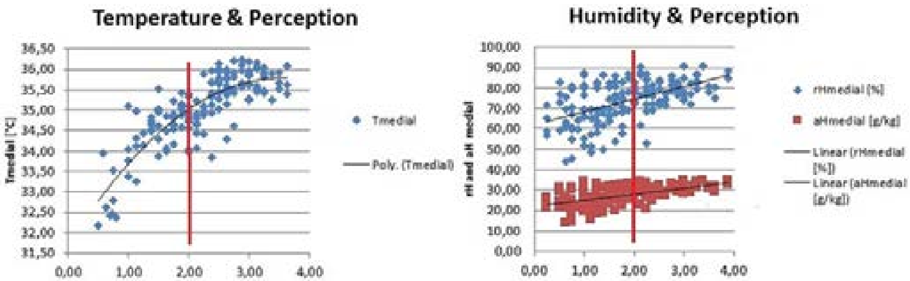

Fig. 6.4. Combined temperature and humidity perceptions of proband test in shoes at various climate and physical stress scenarios.

The so-called "skin-near" microclimate is ultimately determined by the heat and moisture released from the skin, the transfer properties of the air and textile layers next to the skin, and the ambient/room climate. Depending on the spatial extent of this layer system, different climate combinations occur with increasing distance from the skin surface. These are also determined by the heat and moisture transfers generated by the skin due to thermoregulatory circulation and sweating rates, which can be highly variable. Buffer and storage effects due to heat capacities, vaporous moisture accumulations (evaporative capacity) or condensation effects have an additional influence and act time-dependent, both in the formation of a stationary microclimate state (steady state) and during redrying.

In the case of stationary transport processes through a textile layer with known heat and moisture transfer resistance and without or after saturation of the storage capacities, heat and moisture transport are determined only by the temperature and moisture gradient. Assuming a temperature of the sweating skin of 35 °C and 100 % relative humidity, corresponding to a vapor pressure of 56 hPa, and an ambient climate of 20 °C and 50 % relative humidity, corresponding to 11 hPa, the microclimate conditions at each position can be determined or measured with suitable miniaturized sensor technology if the layer geometry (path length for transverse transport) is known (see Fig. 6.5). It must be taken into account that, above a certain sensor size, an additional cavity is created which also influences the thermal insulation, and a possible heat dissipation via the sensor cables may occur. Thus, not only the size and contacting of the climate sensors but also their orientation, i.e., active measurement window faced to the source or to the environment, as well as the location position on the contact surface with the skin are in focus. The latter is of central importance, especially for measurements with single sensors on test persons, since small deviations from the desired sweat-producing area have an effect on the measured humidity values. In addition to reproducible and reliable measured values, there is also a demand for two-dimensional recording of temperature and humidity with miniaturized, dew-resistant climate sensors, which are preferably arranged in a fixed grid and with fixed orientation of the measuring window (no twisting).

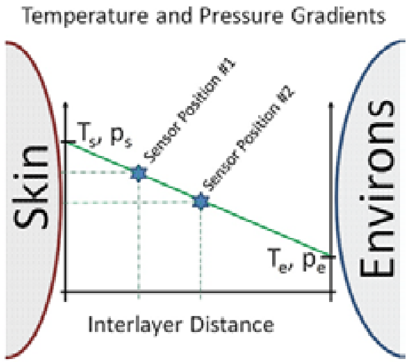

Fig. 6.5. Microclimate at various positions along the gradients of temperature (T) and water vapour pressure (p).

Since thermoregulatory processes in humans are always subject to control dynamics (see Fig. 6.3), which also show inter- and intraindividual scatter, a standardized heat and humidity source should also be used instead of test subjects for reproducible analysis of microclimate states. Only then it will be possible to generate comfort-determining microclimates under steady-state conditions and with high physiological relevance, which are fundamental for reliable comfort predictions.

6.2.1. Sensor Technology

Usually, the measurement of the microclimate is realized with discrete combi-sensors for temperature and humidity [22, 23]. The inaccuracies that occur in sensor location and occupancy or coverage led to a scattering of the measured values and limit the quality of the information. A solution to avoid the difficulties with single sensors is a defined array of up to 60 sensors combined with an interpolation algorithm calculating the temperature and humidity distribution with all discrete sensor readings. To reduce wiring and technical complexity bus-compatible combi-sensors with I2C interface are built into a flexible, thin and compressible spacer mat, which enables two- and even three-dimensional recordings of the microclimates [13].

By laborious market analysis two suitable sensors with different specifications have been identified.

- Honeywell HIH8xxx:
  - I2C with up to 128 programmable addresses;
  - ± 2 % humidity resolution, 0 … 100 % rel. humidity;
  - ± 0,5 °C temperature resolution, -40 … 125 °C;
  - Measures: 4×5×2 mm^3;
  - Read response time ca. 33 ms;
  - Condensation resistant, with or without filter membrane.

- Sensiron SHT3x:
  - I2C with 2 selectable addresses;
  - ±1,5 % humidity resolution, 0 … 100 % rel. humidity;
  - ±0,1 °C temperature resolution, -40 … 125 °C;
  - Measures: 2,5×2,5×1 mm^3;
  - Read response time 4–15 ms;
  - Condensation resistant, with or without filter membrane.

The Honeywell HIH8xxx can be directly implemented in an array on one bus cable, has a sufficient but low resolution in temperature and is bigger than the Sensirion chip. The main disadvantage of the SHT3x is the restricted address range (just 2) for I2C operation with up to 60 sensors on one bus cable. To get it also operated an additional PIC (peripheral interface controller, Microchip corp.) is implemented for each SHT3x which serves as a bus respectively address manager. This solution offers a so-called flash-mode, where converting of all sensors is simultaneously initialized. The collection of the converted temperature and humidity values is then sequentially. This mode makes sure, that the complete sensor array is read within a few milliseconds, while the reading of 30 Honeywell sensors takes about 1 second.

To connect each sensor unit the SMD sensor chips are mounted on a tiny printed circuit board (PCB) which allows also the integration of a special crimp connector for the I2C wires and, in case of SHT3x, of the PIC (see Fig. 6.6). Before implementation the programming of different addresses to HIH8xxx as well as address managing routine to PIC of SHT3x is necessary.

By use of a 4-wire ribbon cable the sensor-PCBs can be arranged in any distance or matrix dimensions very quick. To finish the sensor array it will be prefixed on a spacer material and is sewed and covered by a highly breathable mash material (see Fig. 6.7). The resulting sensor mat is about 4-5 mm thick and has for seat or backrest application a typical dimension of 500×500 mm^2. Compared with single sensor measurement the SWEATLOG mat takes neglectable influence on the microclimate, is highly flexible and confirms mechanical robustness (connector, cable, sensor-PCB) within many tests.

Fig. 6.6. I2C-sensors processed for measuring the microclimate distribution.

Fig. 6.7. SWEATLOG logger and sensor array (mat) with up to 60 HIH8xxx sensors at one I2C ribbon (4 wires).

For application in shoes or other narrow spaces a sensor set with highly flexible wiring is available (up to 16 sensors). To achieve the demands on a valuable and reproduceable measurement the single sensors have to be fixed in a defined position, even for visualization, and orientation, e.g., directly on then test target or by use of a suitable grid.

The SWEATLOG sensor mats as well as wired sensor set are operated by a logger which works either as stand-alone or USB-controlled. In the USB mode the SWEATLOG-app allows an online monitoring and visualisation of the registered values as a heat and humidity map (see Fig. 6.8), otherwise these are processed from the data stored on the internal SD-card.

The visualizations are calculated by use of each sensor value with a special interpolation algorithm to get the continuous heat and humidity distributions. Additional clustering methods supports the processing of the characteristical values of thermodynamical or physiological relevance [13, 17]. Fig. 6.8 shows the typical distribution of a proband sitting on a chair showing the contact zones of the buttock and the upper thighs impressively in the heat map, whereas the map of the relative humidity is nearly homogeneous and in the range of the ambient humidity, seeming that the occupant is not sweating. But a look at the absolute humidity map confirms an increase of the humidity in the microclimate as an indicator for additional slight sweating.

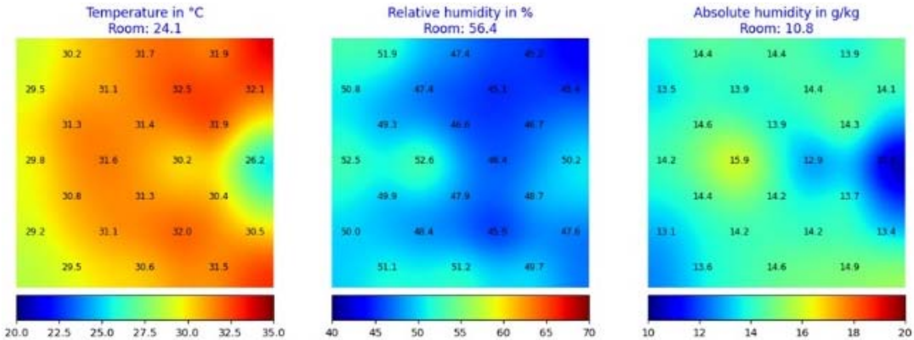

Fig. 6.8. Heat and humidity map of a proband on the seat of an office chair.

6.2.2. Sweating Source

As a consequence of the standardisation demands for climate tests, and of course due to cost extensive proband tests, artificial systems are applied. Those emit heat and humidity aiming to measure and calculate physical material parameters such as heat conduction and vapor transmission respectively storage. Others aim to simulate the human heat and humidity emission (thermoregulation) creating a certain microclimate with the test object, which allows a reliable prediction of the climate comfort [4, 10, 18, 20]. Such climate dummies can be found either as whole-body manikins or formed as single body parts. They are mostly of highly complex technology and sometimes come with instable processes. Standards have been available for decades like Sweating Guarded Hotplate (SGHP) respectively Hohenstein's Skin Model [26] but without a focus on microclimate.

An additional challenge, but not only related to the use of climate manikins, is the standardization of test conditions with view on valid comfort assessments. Unfortunately, no consistent ambient climate conditions, no consistent measurement spots and sensor qualities, no fixation of heat and particularly humidity emissions and last not least no standardized valuation variables can be found in the existing test procedures. So, the interpretation of the corresponding results only remains to be a relative statement based on the subjective experience of the examiner.

Apart from standardized test conditions the particular challenge for the setup and operation of such climate simulation systems is the best possible replication of the physiological human evaporation and the combination of heat and humidity emissions.

Only this way defined climatic conditions and energy rates will ensure realistic heat and moisture flows and stationary microclimate situations.

According to the necessary features of a standardized heat and humidity source the SWEATOR system has been developed [12]. This technology is based on a water-filled, heat controlled hollow body with a specific perforated surface, coated by a special water vapor permeable membrane. This sweating devices can be manufactured in different shapes (see Fig. 6.9), with different permeable membranes and without or with different surface perforations. The heating and water circulation are controlled by a touch screen control unit. Energy inputs from a few Watts to 400 W per square meter and sweating rates between 50 and 600 ml/m²*h are possible.

Fig. 6.9. SWEATOR torso with test jacket, SWEATOR foot and SWEATOR head with safety helmet.

For human physiological simulations under normal conditions, settings of 30-50 W/m^2 or 90-120 ml/m²*h are used. After pre-conditioning the device to the desired values, the SWEATOR manikin is applied to the confectioned test objects. In the boundary layer between SWEATOR surface and material probe the microclimate distribution is measured with single sensors resp. a sensor array at defined locations (see Section 6.2.1). The test trials take place under climatically defined room conditions including additional convections, if necessary. The SWEATOR technology thus enables realistic test conditions and non-destructive testing options with ready-made products.

The SWEATOR control unit records and stores the supplied energies, weight changes and microclimate conditions even within various textile layers or outlets of ventilation channels.

Regarding the thermal system self-loss, the moisture quantity, stored in the sample during the experiment, and the mass flow, converted by use of approximately constant evaporation energy of approx. 2400 J/g, the most important values of heat flow Hc and moisture flow He, each with the unit Watt, are calculated. This means that the result variables:

- Moisture Vapor Transmission Rate MVTR [g/h];
- Evaporative Capacity EC [W];
- Storage from the vapor phase ΔW_P [g];

can be determined. Including the measured microclimate parameters temperature, relative humidity or water vapor partial pressure between two measuring spots even the thermodynamic material parameters:

- Thermal resistance Rct [K*m^2/W];
- Water vapor transmission resistance Ret [Pa*m^2/W];

are calculated (see Fig. 6.10).

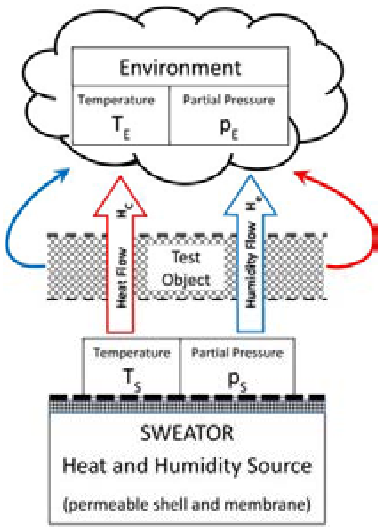

Fig. 6.10. Heat and moisture transport in SWEATOR simulation.

A special feature of SWEATOR technology is the moisture release via a water vapor-permeable membrane, additionally influenced by targeted perforation of the release surface. In contrast to the sweat glands of the human skin, the moisture is released exclusively in the form of vapor and avoids the formation of "wet spots" that can occur with liquid humidity release. These are always an indication of overloading of the moisture removal system, do not describe a desired operating condition and massively change the thermal conductivity value. The maximum vaporous sweating rate is limited by the above-mentioned design features of the SWEATOR dummies, the occurring sweating rate is determined by the partial pressure gradient and moisture transmission resistance. The simultaneous application of heat and moisture and the almost arbitrary shaping of the test specimen guarantee non-destructive product testing (clothing, seat, bed) with high thermophysiological relevance.

6.3. Applications

The following application examples with the SWEATOR heat and humidity source and the SWEATLOG system for measuring temperature and humidity distribution demonstrate application practicability as well as options for evaluating the climatic comfort of clothing components and seating and bedding systems.

6.3.1. SWEATOR and SWEATLOG

Fig. 6.11 shows the results of validation tests with SWEATOR torso and SWEATLOG sensor array. The sensor mat, constructed with a 4 mm spacer (white) and green cover fabric (see Fig 6.7), is placed on a reference mattress (100 mm PU cold foam) and repositioned for each test run. The torso is separately preclimatized to 37 °C core temperature and then placed on the test pad with measuring mat for 90 minutes. The measurements are repeated several times, in each case with the sensor openings oriented towards the torso or toward the pad. The final steady-state values of the evaluated cluster sizes in the central contact area of the torso sweating body, covered by 4 sensors, are summarized in Table 6.1.

The reproducibility of similar test setups is in the range ±0.12 °C and ±0.4 % relative humidity or ±0.25 g/kg absolute humidity. Sensor orientation has virtually no effect on temperature but shows a reduced relative humidity of 87.6 % and 34.25 g/kg absolute humidity, respectively.

Table 6.1. Steady state values with mean value (MV) and standard deviation (SD) after 90 minutes in the central cluster (each test 4 times).

Test run	Temperature [°C]	Rel. humidity [%]	Abs. humidity [g/kg]
“to the source” #01	35.85	99.1	38.6
“to the source” #02	35.85	99.4	38.7
“to the source” #03	35.65	99.9	38.5
“to the source” #04	35.90	99.9	39.0
MV / SD	*36.81 / 0.11*	*99.57 / 0.39*	*38.70 / 0.21*
“to the pad” #11	35.99	87.8	34.5
“to the pad” #12	35.97	87.5	34.3
“to the pad” #13	35.75	87.6	33.9
“to the pad” #14	35.97	87.5	34.3
MV / SD	*35.92 / 0.11*	*87.6 / 0.14*	*34.25 / 0.25*

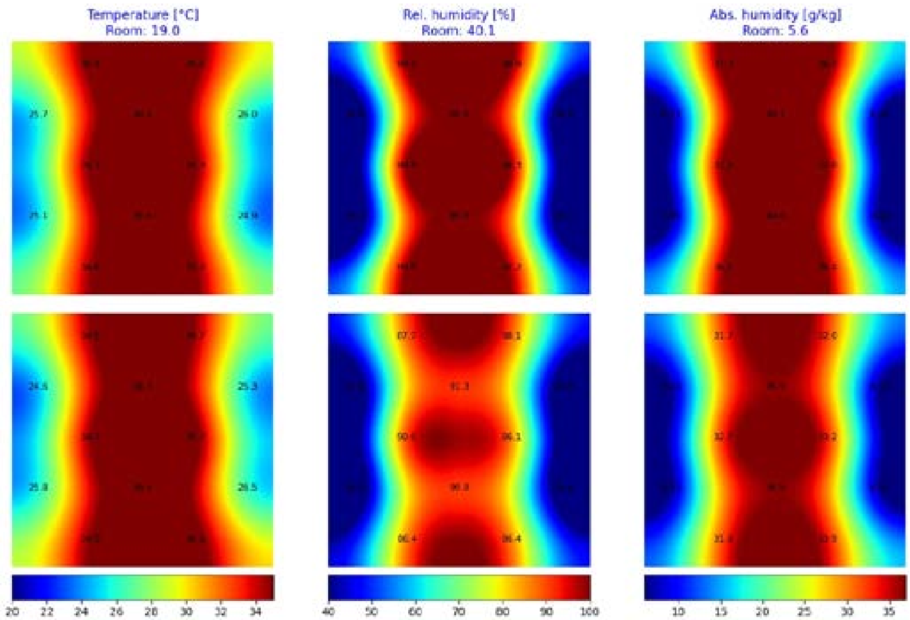

Fig. 6.11. Heat and humidity map by SWEATLOG mat, sensor window facing to source (above) resp. turned away from source, i.e., facing the pad (below).

The combination of standardized heat and humidity source (SWEATOR torso) with two-dimensional recording of the temperature and humidity distribution guarantees high reproducibility of the occurring microclimates. The influence of the sensor orientation between "to the source" and "to the pad" is accompanied by a difference of about 12 % relative humidity and is also highly reproducible. An influence of the green cover fabric on the climate measurands could not be determined.

6.3.2. Validation of Proband and SWEATOR Test

The focus of the SWEATOR simulation combined with SWEATLOG sensor mats is primarily set on the analysis of heat and moisture transport routes and, in particular, on the generation of realistic microclimates for direct comfort assessments. This requires, on the one hand, a secure mapping between regional microclimate conditions (seat, bed, jacket, etc.) and the corresponding comfort sensations of the users, and on the other hand, the appropriate choice of parameters for the simulation system.

For this purpose, a variety of studies on comfort correlations in seating systems, footwear and apparel components could be linked to the comfort areas. After evaluation and harmonization of the rating scales (e.g. [25]), the transition temperature and humidity were determined to reach discomfort in warm temperatures at about 35.5 °C respectively 25 g/kg [12].

The results in Fig. 6.12 emphasize the correlation between human subject and simulation test as well as to the perceptions of the various climate situations (test phase) appearing on car seats with active cooling systems during driving. As expected, the humidity perception is weak, but the temperature and especially the comfort perception, combining heat and humidity, presents a very good correlation.

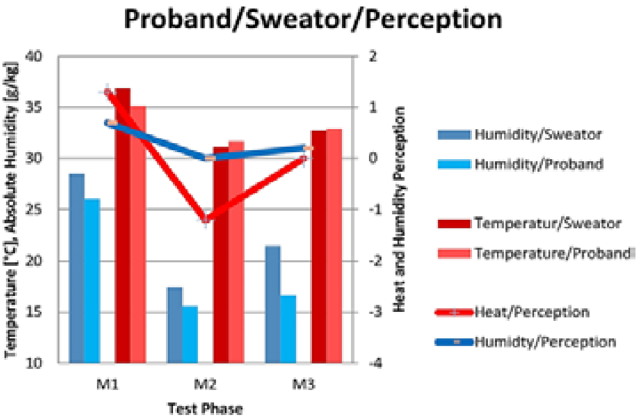

Fig. 6.12. Comfort correlation of proband and simulation results from seating tests.

6.3.3. Skin Integrity on Mattresses

Optimized lying systems, i.e., bedsteads with mattresses and covers, are a basic prerequisite for physical rest. In addition to special hygienic requirements, this system is of decisive importance in the care sector due to lengthy periods of lying and use. The focus is on skin integrity with the prevention of decubitus diseases, which can be a cause of continuous exposure to pressure in combination with a warm and humid climate. The weakened skin areas show degenerative changes with subsequent pressure ulcer formation even at low pressure levels. The key factors in preventing such diseases are therefore pressure reduction and pressure shifting (repositioning of patients) as well as optimized moisture management, possibly supported by technical means such as ventilation channels in the mattress or the use of special bed covers.

Fig. 6.13 shows the clustered microclimate variables temperature and absolute humidity under two different duvets on identical bedding systems. The Heat Index HI, determined by temperature and humidity as an indicator for climate perception and comfort perception, is shown as an additional climate qualifier. While the final values of the temperatures of both duvets hardly differ, already for the absolute humidity's a clear distinction is to be determined on the basis of the comfort limit of 25 g/kg. This is even more evident in the HI, which shows a significantly higher heat perception for duvet no. D2.

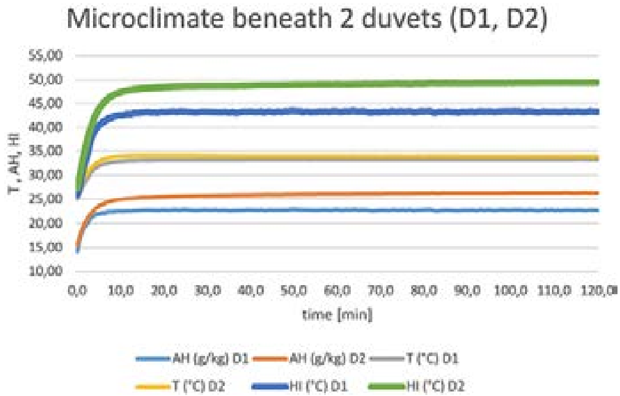

Fig. 6.13. Microclimate management (T: temperature, AH: absolute humidity) and Heat Index (HI) at 2 bedding systems.

6.4. Conclusion

Although microclimate is only one aspect when it comes to look at comfort determining factors, it decisively gains importance with increasing wearing or using cycles of apparel, seating and laying systems. Therefore, microclimate requirements already need to be considered in the planning and construction phase of apparel and body support systems. One of the challenges arising is the complex validation of climate comfort with test and evaluation standards to guarantee reproducible and comparable results as well as reliable forecasts. Extensive research work and data analysis at Munich University of Applied Sciences (MUAS) provide valid correlations between simulation results, tests with human occupants and their perception of comfort.

To gain a better understanding about climate comfort it seems relevant how intensely heat and vapor accumulate within the skin near microclimate because the microclimate directly affects the human heat sensation and under standard conditions allows to quantify it. Thermodynamic indicators should not only be conducted to reflect extreme conditions (e.g., maximum possible flow rate) but conditions under realistic wearing or using trials to reflect the 90 % of time in which the products are used.

The requirements on climate product testing can only be met economically with human-physiologically adapted simulation systems. Based on physiologically required heat and moisture release properties, simulations must also offer simple technology, practicability and result validity. The SWEATOR technology developed at MUAS in cooperation with Inside Climate GmbH covers a large part of the requirements mentioned and provides sweating manikins with different shapes adapted to human physiology for use on material samples and on ready-made textile products. Numerous measurement results confirm simple use, the valid determination of basic quality parameters such as Ret and Rct as well as microclimate simulation highly correlated to real using scenarios.

Apart from the simulation technique the decisive point, however, is a reproducible and valuable measurement of the appearing skin near microclimate, recorded in the boundary layer close to the skin and correlated to probands perception,

Regarding the demands on the microclimate sensor, i.e., precision, placement, orientation and at least reproducibility, special measuring methodologies have to be applied. The SWEATLOG system uses combined temperature and humidity sensors with I2C interface placed in a defined array and fixed in a flexible mat. The visualization as a heat and humidity map is realized by use of selected algorithms. Interesting thermodynamical as well as comfort related microclimate values are calculated within defined cluster areas.

The unique combination of SWEATLOG sensor mat and the SWEATOR system with anatomically formed and sweating manikin creates the basis for thermophysiological product analyses. Combined with differentiated evaluation methods and with correlations to human comfort perceptions, a reliable comfort prognosis for assessment as well as improvement of clothing or body support products like seats or beds can be achieved.

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