The Role of Tests and Manikin in Defining Fabrics Thermal Characteristics

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Abstract:

Testing plays an important role in maintaining the competitiveness of a company, especially in a highly competitive sector such as the textile industry. Fabric testing can be carried out to measure aspects of the objective quality of a product and to ensure that the product is fit for the purpose intended. It also ensures that a product complies with defined standards. This study is designed in such a way to provide a wealth of information on fabric testing with full body thermal manikin methods. The study has managed to highlight the latest products from a range of companies . The study has concluded that, thermal manikins are definitely a useful tool to assess and understand the thermal behavior correctly. It may guide garment designers to correct selection of material and could be of much help in reducing occupational accidents happen due to wrong clothing

Keywords:
- ***Thermal manikin ,***
- ***Measurement standards ,***
- ***Fabric testing***
- ***Thermal Characteristics***

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1. Introduction

Thermal manikins are devices by means of which it is possible to simulate heat exchange between the human and the environment. The first one was a one segment copper manikin made for the US Army in the early 1940s of the 20th century [1, 2]. From the very beginning, this thermal measurement device was designated for the clothing industry, mainly in the design of specialized clothes, primarily for the Army [3]. Hence development of the structure of a thermal manikin reflected the specificity of this branch of industry. In the ensuing years further modifications of the structure of manikins were introduced, i.e. the number of segments (parts of the body) of a manikin was increased, and the possibility of simulating movement and the sweating process were introduced [4 - 6].

Presently thermal manikins are used in the clothing industry to determine clothing and sleeping bag thermal insulation [7], as well as the parameters of a surrounding environment in which the use of a sleeping bag will not cause the cooling or overheating of the body [8,9]. Furthermore they are used to assess thermal comfort during work performed in clothes in a given thermal environment, to test heat and water vapor transfer through clothing etc. There are also standards developed for testing clothing insulation and clothing evaporative resistance [10,11].

2. History of Thermal Manikins

For more than 60 years, thermal manikins have served researchers in the evaluation and investigation of thermal transfer associated with clothing, garment ensembles and garment treatments designed to cover the human body and its‟ complex 3-dimensional form [1]. Thermal manikins were originally designed to investigate the thermal interaction of the human body with its environment, particularly in the design and fabrication of clothing due to their intrinsic thermal properties. The number of manikins being manufactured and used and the organization of international meetings specifically devoted to thermal manikin applications indicate the growing interest in using thermal manikins in research and measurement standards [1]. The first human shaped thermal manikin made for the US Army in the 1940‟s was a one-segment, construction of electroplated copper, with electrical circuits that uniformly heated the surface [12,1,13].

The demand for more detailed and concise information instigated the construction of manikins with several, independently controlled segments over the body surface. Other materials have been incorporated in the production of modern manikins in the endeavor to attain a more representative measurement associated with the maintenance of heat balance attained by a human body, while reducing cost and weight. Today, the majority of the thermal manikins have more than fifteen segments [13]. Thermal manikins have evolved from an analogue, one-segment non-

movable, copper man to digital, multi-segmented, movable, and articulated, thermal manikins constructed from a variety of 29 materials that provide relevant, reliable and accurate measurements of heat losses of not just flat 12 x 12 sets of layered fabrics, but of three dimensional garment ensembles as they perform on a movable human shape. Thermal manikins can be exposed to extreme conditions under which a human body could not survive.

3. Application Areas of Thermal Manikins

A thermal manikin is a useful tool to evaluate thermal environments such as clothing, houses and others [1].

The main application fields for thermal manikins are as follows:

- Evaluation of clothing
  - thermal properties (insulation and evaporation. resistance)
  - protection (fire, radiation, rain)
- Evaluation of HVAC-systems
  - buildings
  - vehicles
  - incubators
- Evaluation of indoor air quality
- Simulation of human occupancy
- Physiological simulation
- Other applications [14].

4. International standards and thermal manikins

An increasing number of international standards specify tests with thermal manikins. Most of them deal with the determination of thermal insulation of clothing.

4.1.Standards describes test method with thermal manikin

ISO 9920 - Estimation of thermal insulation and water vapor resistance of a clothing ensemble

- This test standard specifies methods for estimating the thermal characteristics (resistance to dry heat loss and evaporative heat loss) in steady-state conditions for a clothing ensemble based on values for known garments, ensembles and textiles. It examines the influence of body movement and air penetration on the thermal insulation and water vapour resistance.

- ISO 14505 - Evaluation of the thermal climate in vehicles, part 1 and 2
  - ISO 14505-1 gives guidelines for the assessment of thermal stress inside vehicles used for land, sea and air operation. It offers information about the assessment of hot, cold as well as moderate thermal environments by referring to different methods, as specified in International Standards, and specifying the constraints and necessary adjustments needed for the special case of vehicle climate assessment.
  - ISO 14505-2 provides guidelines for the assessment of the thermal conditions inside a vehicle compartment. It can also be applied to other confined spaces with asymmetric climatic conditions. It is primarily intended for assessment of thermal conditions, when deviations from thermal neutrality are relatively small.

ASTM F1291- Standard method for measuring the thermal insulation of clothing using a heated thermal manikin .

- This test method can be used to quantify and compare the insulation provided by different clothing systems. For example, variations in the design and fabric used in component garments can be evaluated. The effects of garment layering, closure, and fit can be measured for clothing ensembles. The insulation values for ensembles can be used in models that predict the physiological responses of people in different environmental conditions.

- ASTM F2370 - Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin.
  - This test method can be used to quantify and compare the evaporative resistance provided by different clothing systems. The evaporative resistance values for ensembles measured under isothermal conditions can be used in models that predict the physiological responses of people in different environmental conditions.
- ASTM F1720 - Standard Test Method for Measuring Thermal Insulation of Sleeping Bags Using a Heated Manikin
  - his test method covers determination of the insulation value of a sleeping bag or sleeping bag system. It measures the resistance to dry heat transfer from a constant skin temperature manikin to a relatively cold environment.
- EN 342 - Protective clothing against cold
  - The standard specifies requirements and test methods for performance of clothing ensembles (i.e. two piece suits or coveralls) and of single garments for protection against cold environments. Cold environments are characterized by the combination of humidity and wind at air temperature below -5°C.
- EN 511- Protective gloves against cold

- This standard applies to any gloves to protect the hands against convective and contact cold down to –50 °C.

- EN 345 - Safety footwear for professional use
- Requirements for safety footwear fitted with toecaps designed to give protection against impact.

- EN 397 - Specification for industrial safety helmets
- This European Standard specifies physical and performance requirements, methods of test and marking requirements for industrial safety helmets. The mandatory requirements apply to helmets for general use in industry.

4.2. standards requiring value from manikin tests

- ISO 7730 - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
- This standard presents methods for predicting the general thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments.

- ISO 7933 - Analytical determination and interpretation of heat stress using calculation of the predicted heat strain
- This standard specifies a method for the analytical evaluation and interpretation of the thermal stress experienced by a subject in a hot environment. It describes a method for predicting the sweat rate and the internal core temperature that the human body will develop in response to the working conditions.

- ISO 11079 - Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects.
- This standard specifies methods and strategies for assessing the thermal stress associated with exposure to cold environments. These methods apply to continuous, intermittent as well as occasional exposure and type of work, indoors and outdoors. [15 , 16]

5. Thermal Manikins

A Thermal Manikin is a complex, delicate and expensive instrument with some added features as per the requirement. The thermal manikins are customized as per the purpose of usage. There are about 100 thermal manikins in the world, mostly developed by research institutions and laboratories.

5.1. Newton Thermal Manikin

Thermal manikin “Newton” was produced by Measurement Technology Northwest Company in United States, which is constructed of a thermally conductive aluminum filled carbon epoxy shell with embedded heating and sensor wire elements, (Figure 1).

There are three types of segments “Newton” at present, 20 zones, 26 zones and 34 zones. “Newton” was developed using advanced CAD digital modeling to ensure repeatability in manufacturing. The system is built in accordance with ASTM and ISO standards to meet the garment evaluation needs of testing institutes, clothing, and sleeping bag manufacturers. “Newton” is fully jointed, providing motion at the ankles, elbows, knees, and hips to allow virtually any possible body poses.[17]

Figure.1 “Newton” thermal manikin

5.2. NEMO Manikin

A “NEMO” fully submersible thermal manikin manufactured by Measurement Technology North West (MTNW) (Figure 3). Its stature represents a 50th percentile adult North American male, weighting 71 kg. The manikin shell is made of aluminum and has 23 independently heated thermal zones. Each thermal zone is equipped with heaters to generate uniform heating of the aluminum shell and two precision thermostats to measure skin temperature.[18]

This completely waterproof, submersible, true-weight manikin is rated for immersion testing to depths of 10 feet (3 meters), allowing realistic testing of diving gear, marine survival suits, and other protective garments.

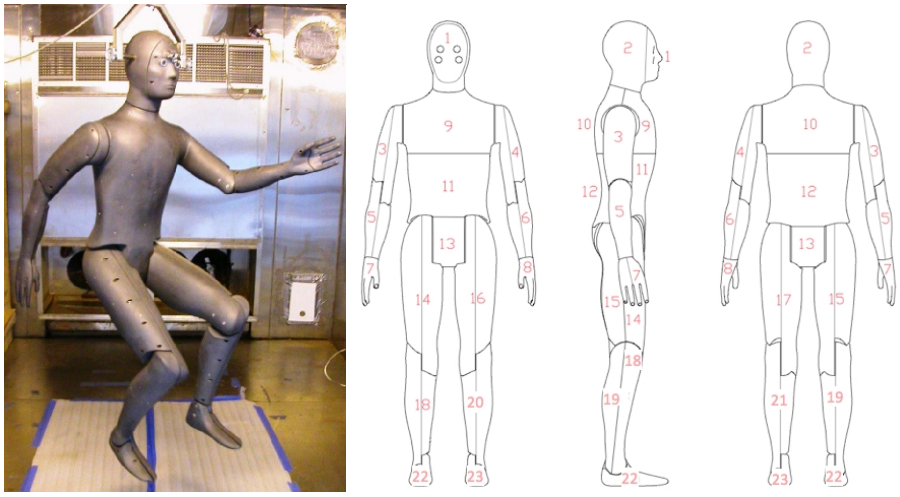

Figure 3. NEMO 23-zone submersible thermal manikin.

5.3. Charlie thermal manikin

Sleeping bags intended for use at very low temperatures have to fulfill certain safety aspects, especially concerning the thermal insulation, in order to allow a safe and comfortable sleep. Even at low ambient temperatures when one tends to feel cold a certain amount of moisture is released from the body. This moisture normally released in a gaseous state to the ambient air is transported through the textile layers in which it could condense or even freeze. The evaporation of sweating water extracts a considerable amount of energy from the body.

To be able to judge the thermal properties of a sleeping bag in a practical manner the whole system consisting of human subject, clothing, sleeping bag, supporting layer, ground and ambient conditions have to be taken into account. The chosen place to sleep can play a crucial role protecting the sleeper from wind and foul weather. Furthermore it has to be considered that the thermal properties of a human and the environmental conditions can vary over a wide range.[19]

Figure 4: The articulated manikin, "Charlie 3", measures the thermal insulation of sleeping bags

Two test centers - Institute Hohenstein and IFTH, joined together to harmonise their test methods and agree on a common standard to evaluate sleeping bag insulation. This became the standard that developed into EN 13537. Charlie became the benchmark manikin for the EN standard.

"Charlie3" is used to measure the effective thermal insulation of the sleeping bag for the sleeper in a climatic chamber under defined conditions (figure 4). In an extensive research project, scientists at Hohenstein developed a physiological evaluation model in the early 1990s that could be used to derive the thermal range of utility of a sleeping bag from these thermal insulation values. Its surface temperature is controlled separately for 16 individual body segments. This took into account the fact that the temperature distribution on the human body varies considerably. In order to feel comfortable, this should be at around 30 ºC on the head and around 34 ºC on the trunk. The skin temperature should be around 32 ºC on the forearm, on the other hand.[20]

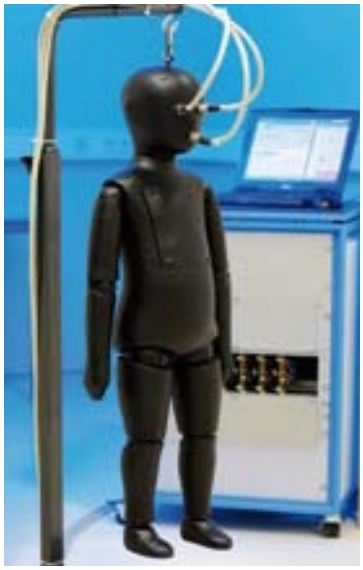

Figure 5. Charlene , child manikin

5.4. Child Thermal Manikin

Due to the lower mass of a child's body it can only produce less thermal energy than the body of an adult.

In addition, children's thermo-regulation ability is by no means fully developed, meaning that the body may react slowly or may not react at all to changes in ambient temperature. What is more, all their sweat glands have yet to become active. As a result, the risk of becoming chilled or overheating is disproportionately greater than it is for adults.

These physiological differences are especially important for the construction of bedding. With the help of „Charlene", a thermally segmented mannequin (figure 5) developed at the Hohenstein Institute, the sleeping comfort of children's bedding can be evaluated and optimized with respect to the special physiological needs of children. „Charlene" who weighs 20 kilograms and is 92 centimeters tall simulates the heat generated by the human body with the aid of a computer controlled heating system. For a child to stay comfortably warm beneath the bedcovers, the amount of thermal insulation of children's bedding must be increased accordingly. „Charlene" is made of synthetic materials rather than copper. A computer-controlled heating system makes it possible to regulate independently the heat generated by six different segments of the body.[20]

5.5. Automotive manikin

ADAM (Figure 6) is a sophisticated surface sensor that interacts with his environment. He was built by Measurement Technology Northwest (MTNW) in Seattle, Washington. He responds to thermal inputs such as radiation and convection and affects the environmental flow and temperature fields. He was designed with the following general capabilities and characteristics:

Figure 6. ADAM, the advanced automotive manikin

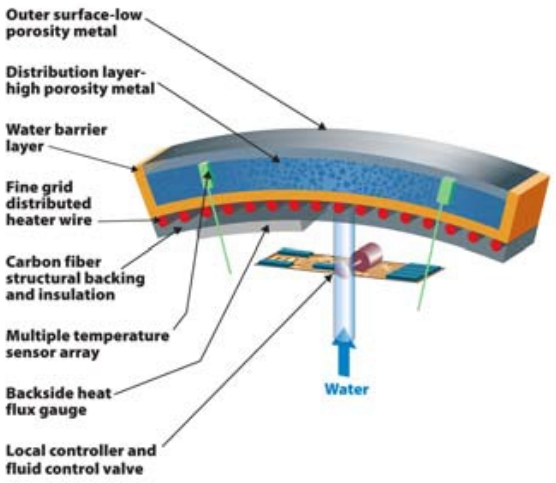

Figure 7. Manikin Segment

- Detailed spatial and rapid temporal control of surface heat output and sweating rate
- Surface temperature response time that approximates human skin
- Realistic and uniform sweating
- Human-like geometry and weight with prosthetic joints to simulate the human range of motion
- Breathing with inflow of ambient air and outflow of warm, humid air at realistic human

respiration rates
- Complete self-containment, including battery power, wireless data transfer, and internal sweat reservoir for at least 2 h of use with no external connections
- Rugged, durable, low-maintenance construction.

The manikin's fundamental components are the 126 individual surface segments, each with a typical surface area of 120 cm2. Each segment (Figure 7) is a standalone device with integrated heating, temperature sensing, sweat distribution and dispensing, heat flux gauge, and a local controller to manage the closed-loop operation of the zone. The high thermal conductivity of
the all-metal construction of the sweating surface yields increased thermal uniformity and response speed. A high porosity layer within the surface provides lateral sweat distribution while the lower porosity exterior promotes uniform sweat across the surface. Distributed resistance wire provides uniform heating across the zone surface. [21]

Figure 8. Sherlock thermal manikin

5.6. Sherlock thermal manikin

A new sweating thermal articulated manikin, built to look like a 175 cm tall man and with fully jointed limbs, has been named 'Sherlock' (figure 8) by customers and employees of the Hohenstein Institute.

With the sweating thermal articulated manikin 'Sherlock', it is possible to measure both the thermal insulation and the breathability of clothing of all kinds using one measuring system, the Institute reports.

The thermal articulated manikins all work in closely controlled conditions in a climate chamber. Different ambient temperatures and humidity levels can be simulated, along with other external influences such as wind, radiated heat and rain.

Hohenstein experts can imitate all kinds of realistic wearing situations, from Arctic expeditions to desert treks.

The manikin can also sit down, meaning that in future it will be possible to use the manikin to test seating of all kinds, including office chairs, car seats and aircraft seats.[22]

6. Discussion and Conclusions

The use of thermal manikins in research and setting standards has significantly increased in recent years. New fields of application such as evaluation of HVAC-systems in rooms and vehicles have grown. Thermal manikins have found their application not only in research but also in test houses and industrial test laboratories.

Thermal properties of fabrics play vital role in providing comfort to the human body. Wrong assessment of performance level of clothing may cause serious psychological as well as physiological problems. The correct measurement of thermal behaviour of fabrics is very crucial for risk assessment in extreme climate also. This deals with ergonomic properties and requirements of clothing, making it more user friendly with providing protection.

The significance of achieving comfort in fabrics was not given much importance in earlier times but the demand for better performance has increased interest in this area. So, the correct analysis, understanding and selection of right material that serves the requirement and meet the required performance standards is need of the hours. Thermal manikins are definitely a useful tool to assess and understand the thermal behaviour correctly. It may guide us for correct selection of material and may reduce occupational accidents happen due to wrong clothing.

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