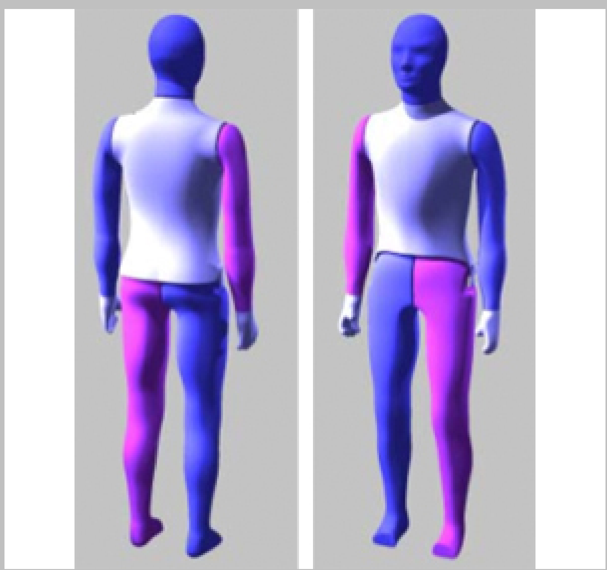
Standards to Assess Thermal Behaviour of Textile Materials and Role of Thermal Manikins



By:
Manoj Tiwari

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By: Manoj Tiwari

Dept. of Fashion Technology National Institute of Fashion Technology Gandhinagar

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Thermal Comfort of Textile Materials and Its Assessment in dynamic environmental conditions has been discussed in previous two articles. For the correct assessment of the thermal properties, global testing standards are must. These standards are not only useful for thermal assessment but also used for comparison of various products at same platform and are accepted unambiguously. The article discusses various popular standards used for different products in different environmental conditions. Thermal manikins have proved to be a useful tool in simulation of human body while testing of thermal properties in varied environmental conditions. Some popular thermal manikins have also been discussed in this article.

Thermal Testing Standards

For a comparison a reference point is needed, which can be taken as benchmark to compare the parameters for a given product. Any property or parameter can be evaluated against the standard provided that the standard is developed with consensus and acceptable by all. It may be a characteristic, property or parameter like length or with of any object or colour of any object.

Targeting this objective, same is followed with the testing standards also. Different material's performance can be tested or evaluated differently, but to keep all the results on one platform and for true judgement, the procedure of testing, specifications, equipment used, testing conditions has to be uniform and well defined.

So, if the test has been conducted by following the standard instructions as described in the procedure, the results will not vary with the change of testing location, person, equipment etc.

In the thermal testing of textile materials various test standards are developed and are globally valid.

There are different agencies/certification bodies that develop and maintain the standards, some of the popular testing standards agencies are:

- ASTM (American Society for Testing and Materials) and AATCC (American Association for Textile Chemists and Colourists) for USA
- BS (British Standards) for United Kingdom
- CAN for Canada
- DIN (deutsches institut fr normung) for Germany
- EN for the EEC (European Economic Community)

- JIS(Japanese Industrial Standards) for Japan
- AS (Australian Standards) for Australia
- BIS - Bureau of Indian standards
- NFPA- National Fire Protection Association

ASTM Standard definition

As used in ASTM, a standard is a docum1nt that has been developed and established within the consensus principles of the organization and which meets the requirements of ASTM procedures and regulations. Full consensus standards are developed with the participation of all parties who have a stake in the standards' development and/or use.[1]

There are various test standards for thermal properties of textile materials and accessing their performance, brief about some of the standards is as below-

ASTM D1518 - For Thermal Transmittance of Textile Materials

This test standard is to determine the overall thermal transmission co-efficient which is the result of a conduction, convection, and radiation for dry textile materials like, fabrics and other materials. It measures the time rate of heat transfer from a warm, dry, constant-temperature, horizontal flat-plate up through a layer of the test material to a relatively calm, cool atmosphere.

ASTM F1868 - For Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate

This test method covers the measurement of thermal resistance and evaporative resistance under steady-state conditions for textile material and clothing.

ASTM F1930 - For Evaluation of Flame Resistant Clothing for Protection against Flash Fire Simulations

Using an Instrumented Manikin. This test method is used to determine the thermal protection provided by different materials, garments, and clothing ensembles on a stationary manikin in a simulated flash fire environment with controlled heat flux, flame distribution, and duration.

ASTM D7024-04 -For Steady State and Dynamic Thermal Performance of Textile Materials

This method provides for the determination of the steady state thermal resistance of a fabric or layers of textile materials. It is useful to set criteria for establishing thermal and comfort parameters for textiles used for clothing.

ASTM F1291-05 - For Measuring the Thermal Insulation of Clothing Using a Heated Manikin

This test method is used to quantify and compare the insulation provided by different clothing systems. 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. This test method is used for the determination of the insulation value of clothing systems and it describes the measurement of the resistance to dry heat transfer from a heated manikin to a relatively calm, cool environment.

ASTM F1720-06 - For Measuring Thermal Insulation of Sleeping Bags Using a Heated Manikin

This test method is used to quantify and compare the insulation provided by sleeping bags or sleeping bag systems. This is used to measure the thermal resistance to dry heat transfer from a constant skin temperature manikin to a relatively cold environment.

ASTM F2370-05 - For Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin

This test method can be used to quantify and compare the Moisture-vapor transmission values and evaporative resistance for clothing systems. The evaporative resistance values for clothing are measured under isothermal conditions used to predict the physiological responses of people in different environmental conditions. It provides guidelines for the measurement of evaporative heat transfer resistance from a heated sweating thermal manikin to a relatively calm environment. It specifies the configuration of sweating thermal manikin, test protocol, and test conditions.

EN 342 - Ensembles and garments for protection against cold (walking manikin test)

This standard specifies requirements and test methods for evaluating the performance of clothing systems or single garment for protection against cold environments. A walking thermal manikin system is required to fully comply with the EN 342 standard.

EN 511 - Protective gloves against cold

This testing standard defines the requirements and standard procedure for evaluating gloves used for protection from extreme cold.

EN 13537· Thermal properties of Sleeping Bags

This test method provides guidelines to measure the thermal properties of a sleeping bag in which a thermal manikin is used as a measuring device, positioned inside a sleeping bag and placed in controlled cold conditions and a standard thermal insulation value of the sleeping bag is determined.

ISO 11 092/EN 31092 - Measurement of thermal and water vapor resistance under steady-state conditions (sweating guarded-hotplate test)

This method provides guidelines for the measurements of Thermal and water-vapor resistance for textile materials and clothing, quilts, sleeping bags, upholstery etc.

ISO/DIS 15831-Measurement of thermal insulation by means of a thermal manikin

This standard provides the guidelines for the requirements of the thermal manikin and the test procedure used to measure the thermal insulation of a clothing system for a walking manikin.

NFPA 1971 - Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting

This standard specifies the minimum design, performance, testing, and certification requirements for structural fire fighting protective ensembles and ensemble elements that include coats, trousers, coveralls, helmets, gloves, footwear, and interface components.'

Thermal Manikins

For the correct and real assessment of the textile material, tests need to be performed in real situations, in case if it is not possible, tests are to be done in simulated environment in the laboratories as the real environment.

Thermal manikins are one of the most advanced and sophisticated testing tools for thermal behaviour assessment.

Thermal manikins can be said as the simulation of human body or artificial human body. These are used to study and analysis of the combined effect of heat and moisture transport on the thermal behaviour of the textile materials and clothing. The human body have different surface temperature at different places of body based on the available surface area for heat and moisture transfer, which need to be taken in consideration while performing the tests. Tests done on sweating hot plates doesn't include that and apart from it these tests are done flat plates, which doesn't give the correct results for thermal behaviour. Apart from it wind velocity, human body movements (sitting, walking, running or sleeping) have different impact on the thermal properties of clothing. A thermal manikin can provide these facilities or Simulation of ideal conditions for testing.

History of Thermal Manikins

Most probably the word Manikin was originated from the Dutch word "Manneken", which means a small man. In French "Mannequin" is referred for a jointed wooden dummy. The first manikin "Manichino" was developed in Italy at the end of the 15th century and it was used as a reference tool to learn the basics of figure drawing.'

Initial prototypes for Thermal manikins are reported to be developed in the years of Second World War by the US military and credit goes to Dr. Harwood Belding (1941) at Harvard Fatigue Lab for the same. Before these prototypes guarded ring flat hot plates were used to measure the thermal properties of textile materials, later some vertical metal cylinders with some perforations were developed, it was actually an effort to simulate human trunk. The initial manikin was crude, headless and armless cylinder from stovepipe and various sheet metals. It was equipped with a simple internal heater and fan to distribute the heat.

Later in 1942, General Electric Company (GE) developed a thermal manikin by electroplated copper shell of thickness of 3.0-6.0 mm. This model was equipped with an electrical circuit to maintain the uniform skin temperature with option of temperature variation in head and feet. 4

In 1945, GE developed some modified manikins for Climate Research Laboratory and Aero Medical laboratory, this manikin was developed by using anthropometric measurements and primarily used for studying the thermal properties of textile materials.[3]

Based on the requirements modifications were done in the manikins design and functioning. The initial developments were focussed on detailed measurements used for manikins. Later temperature control systems were incorporated and multi segment manikins were developed in the early 1950's.[6]

By the end of 1960's some important developments took place in the form of the development of a manikin with a cooling device by which measurements of thermal transportation and surface temperature behaviour due to convection and radiation of heat were studied. In the same decade Woodcock(1962) at USARIEM(United States Army Research Institute for Environmental Medicine) worked on moisture permeability index, This parameter characterized the permeability of clothing materials to the transfer of water vapour, This was actually the incorporation of manikins to the breathing system. Later Goldman and Breckenridge developed Breathable / Sweating manikins with tightly fitted cotton strips on outer surface that could be saturated with water to simulate a sweat wetted skin surface. After this development some experiments were initiated to increase breathability of chemical and biological protective clothing.

In 1970's a French manikin was constructed based on the same concept with a cooling technique to measure the heat gain and used for the assessment of heat protective cloth ing.[7]

Table 1: Milestones in the Development of Thermal Manikins [3]

Sr No	Year	Country	Series	Segment	Material	Regulation	Posture
1	1942	USA	SAM	1-segment	Copper	Analogue	Standing
2	1964	UK	ALMANKIN	11-segment	Aluminium	Analogue	Standing
3	1972	France	CEPAT400	11-segment	Aluminium	Analogue	Standing
4	1973	Denmark	HENRIK2	16-segment	Plastic	Analogue	Movable
5	1978	Germany	CHARLIE	16-segment	Plastic	Analogue	Movable
6	1980	Sweden	SIBMAN	16-segment	Plastic	Digital	Sit/Stand
7	1982	Sweden	VOLTMAN	19-segment	Plastic	Digital	Sitting
8	1983	Sweden	ASS MAN	36-segment	Plastic	Digital	Sitting
9	1984	Sweden	TORE	19-segment	Plastic	Digital	Movable
10	1987	Sweden	CLOUSSEAU	7-segment	Plastic	Analogue	Standing
11	1988	Finland	COPELIUS	Sweating Manikin	Plastic	Digital	Movable
12	1989	Denmark	NILLE	Female Manikin	Plastic	Comfort	Movable
13	1991	Sweden	HEATMAN	33+3-segment	Plastic	Multi	Sitting
14	1991	Hong Kong	WALTER	1-segment	Fabric	Water	Movable

15	1995	France	HEATMAN	36-segment	Plastic	Digital	Movable
16	1996	Denmark	NILLE	Breathing Manikin	Plastic	Multi	Movable
17	2001	Switzerland	SAM	Sweating Manikin	Plastic	Digital	Movable
18	2003	USA	TOM	26-segment	Copper	Digital	Movable
19	2003	USA	ADAM	126-segment	Composite	Model	Movable

At the same time Givoni and Goldman developed some thermal equations considering pumping in the manikins to observe and analysis the thermal behaviour change due to stressful environments.[5]

In 1979, Technical University of Denmark modified some of their old manikins with some advanced new generation wiring and control systems. Measurements of water flow and air flow control features were incorporated.[7]

Later in 1980's it was recognised that the tests performed on a static, standing thermal manikin doesn't give the realistic results and have limited scope to actual user conditions. Aiming to achieve realistic simulation multi-segment manikins which were able to sit and walk was developed. Some more robust constructions manikins could even be constantly moveable, i.e. perform "walking" or "cycling" movements.'

Table 1 shows the milestones in the development of thermal manikins.

Making of a Thermal Manikin

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

Some features are most commonly used in thermal manikins, like-simulation of human body heat exchange, measurement of 3-dimensional heat exchange, integration of dry heat losses, and measurement of clothing thermal insulation.

There is very limited information available on making of thermal manikins as the technology is still in laboratories only and limited commercial manufacturing is there.

There is some information available on the material used and the specifications for the manikins developed by Measurement Technology -North West Company, USA and Hong Kong Polytechnic and manikin developed by Technical University of Denmark.

The manikin developed in 1988 by Technical University of Denmark by Peter Trans and the manikin name is PT-Teknik.

Table 2: Technical Specifications for PT-Teknik [8]

Body Height	168cm
Body Weight	20Kg
Power supply	100/240Vin and 24 VDCout
Alternative powering	15-28VDC
Heat loss	Ot0200W/m'
Solution	0,1 W/m'
Precision	1%
Temperature	18t042 Dgr. C
Solution	0,1 dgr.C
Precision	0,2 dgr. C
Frequency	40Hz

The body of this manikin is made of glass fibre and joint made of aluminium rings that work as supporting frame for joints in hands, shoulders, neck, knees and hips. On the surface of the manikin nickel wiring is done and imbedded in a strong and heat conducting polyester. The complete manikin body is painted with a polyurethane colour. The manikin is having detachable parts (I ike hands can be kept separated) for ease in placement or transportation while its not being used.

Each section of the manikins is equipped with microcontroller system to measure the temperature of the surface with a precise control. [8]

The Technical data for PT-Teknik is shown in below table

The manikin is equipped with 2 pumps, 1 for inhale the fresh air and another for exhale, exhale pump is connected with a gas valve. When the exhaling is active, the valve passes the gas to the inlet of the exhale pump, where it is mixed with air. Adding to this the exhale pump is connected with one heater with controller also, by which temperature of the exhaled gas can be controlled.


Figure 1: Front view of the standing "Walter"

The specifications for inhale and exhale pumps are as below[8]-

- Computer interface: RS 485 Control software for MS Windows operating system
- Two pumps are switched on and off to stop and start flow
- Timing: Inhale, wait 1, exhale, and wait 2.
- Tubesouterdiameter:10mm
- 2 Pumps, Dimensions 22 x 18 x 17 cm
- Pump Weight 6.2 kg
- Power consumption max -85W
- Pump Capacity- 70 litre/min depending on tube length.
- Electric requirement: 220 VAC, 50 Hz

US Patent Office has given patent (Patent No. US 6,543,657 B2) for Hong Kong Polytechnic University in 2003 for a thermal sweating manikin named "Walter", which is manikin able to walk.

As per the description given in the patent document, the thermal manikin, Walter has a closed perforated rigid frame which is covered with breathable fabric. There is a flow of water inside the manikin with the help of a pump to simulate the blood flow. The manikin is equipped with controllers and sensors to measure the conditions inside and outside of the manikin for the correct assessment of the thermal behaviour.

According to the patent the skin of the manikin is made of breathable fabric, which has multiple laminated layers, this is made of majorly 3 layers of fabric, outer layer is made of Nylon and inner layer is knitted fabric with a sandwiched layer of Polytetrafluoroethylene (PTFE-TEFLON). These types of fabric are available in the market and known commercial as trade name -"GORTEX". The sensors are attached on the skin outside of the manikin to measure the moisture flow. The temperature sensor is fitted inside of the manikin body: [9]

The key features of "Walter" are-

- Sweating is simulated by a waterproof, but moisture permeable.
- Walter simulates human thermal physiology. The core of Walter's body is controlled at 37°C.
- The body temperature is controlled by the rate of the pumps which supply warm water from the core region to the extremities.
- Thermal insulation and moisture vapour resistance are measured in single step.
- The arms and legs of "Walter" can be motorized to simulate walking motion.
- The skin temperature can be changed to change the required level of sweating from skin and fabric of the skin also can be selected as per the moisture permeability required.

One another thermal manikin is developed by Measurement Technology North West Company, USA, the name of this manikin is "NEWTON", is a multi segment manikin constructed of a thermally conductive aluminum filled carbon epoxy shell with embedded heating and sensor wire elements. NEWTON is available in 3 ranges, which are 20, 26 and 34 segments. It has been made flexible enough with the help of joint, capable of adopting different postures and able to walk also.[10]

Figure 2: Thermal Manikin="NEWTON"

The schematic diagram of standard thermal zones is shown in the below figure (**Fig. 3**) 20 zone manikin

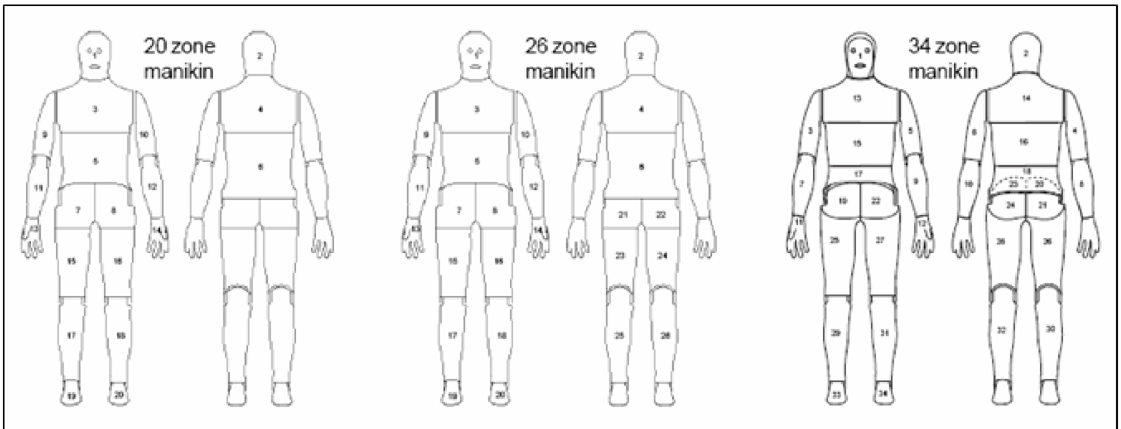

Figure 3: Standard Thermal Zones of "NEWTON"

The "NEWTON" is capable of working in a wide temperature range that is -20°C to +50"C in an environment ofO-100%RH

The accuracy level is ± 0.1 °C temperature measurement and set point control, ± 3% relative humidity measurement with 800 W/m^2 maximum power output.[11]

SIMON is one particular manikin which is used for the assessment of sleeping bags; this has comparatively lesser segments than that of NEWTON. This is also developed by Measurement Technology North West Company.

Figure 4: Thermal Manikin- "SIMON"

The manikin is made of carbon epoxy material and have 13 independent zones with wire sensors fitted on each zone to measure the heat flux and moisture transport. This manikin is also equipped with wind sensors and RH sensor. The accuracy level of this manikin is same as "NEWTON".

NEMO is one special manikin which is a water proof thermal manikin, with an optional sweating skin system. This is developed for assessment of thermal behaviour for water proof clothing can perform underwater till 10ft. depth. This has completely sealed body with waterproof but flexible joints. Power control and fluid cabling is done through eyes. The manikin has 21 zones equipped with wind, RH and temperature sensors.

ADAM (Advanced Automotive Manikin) is one of the most sophisticated and advanced thermal manikin so far, which is used for assessing automobile comfort. This is developed by Measurement Technology North West Company for National Renewable Energy Laboratory, USA.

ADAM (Advanced Automotive Manikin) is one of the most sophisticated and advanced thermal manikin so far, which is used for assessing automobile comfort. This is developed by Measurement Technology North West Company for National Renewable Energy Laboratory, USA.

The manikin has 126 independent segments with porous metal sweating skin and computerised fluid flow control. It's equipped with Real-time measurement of surface temperature and transient heat loss from each zone segment. Heat and fluid regulation is microprocessor controlled and with Internal power regulation to monitor battery condition and battery recharging.

This manikin is cable of working from O°C to +70°C in an environment of 0-100% RH With 500 W/m² maximum power output on batteries and 800 W/m² maximum power output on power cable supply.

Conclusion

Thermal properties of clothing 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 clothing 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 importance of achieving comfort in clothing was not given 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.

Figure 5: Thermal Manikin-"NEMO"

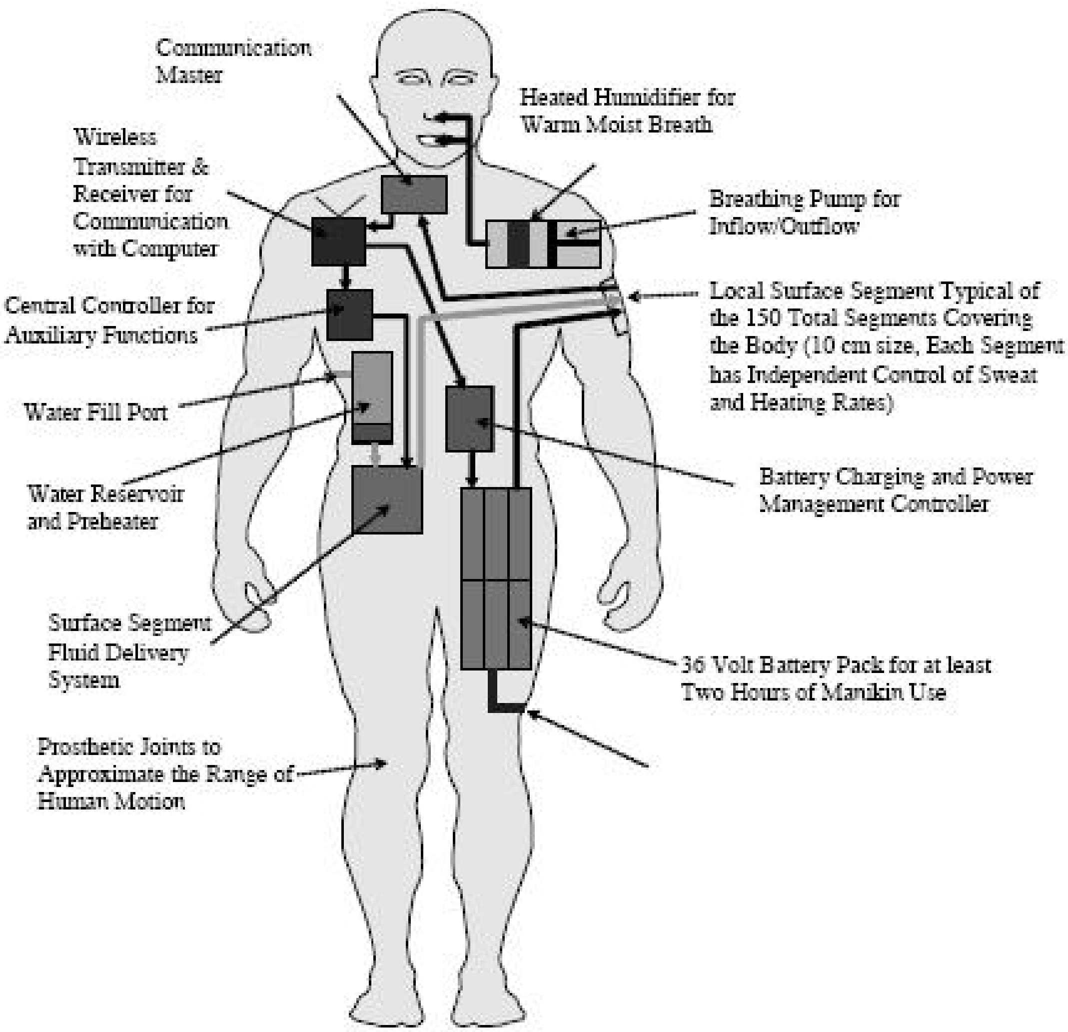

Fig 6: Schematic Diagram of Gadgets and Sensors in ADAM

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