# Microclimate of Smart Garment

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***Abstract*** **–Clothing comfort is a very important aspect of garment quality evaluation. It is especially significant in the designing of smart clothing, where specific design is complemented with the presence of electronic components. The electronic system must provide an additional value for clothing instead of causing discomfort. The article summarizes a number of recommendations for a comfortable smart clothing design, by analyzing human-clothing interaction, processes of heat and moisture conduction, under-garment microclimate, as well as offering constructive solutions for garments and the appropriate use of materials for a better circulation of heat through clothing.**

**Keywords – microclimate, smart clothing, comfort**

## I. INTRODUCTION

When designing comfortable and high quality clothing, it is necessary not only to take into account aesthetic and functional aspects but also to think about the interaction between a garment design and a human body considering its anatomical, physiological and psychological needs [1]. Clothes ensure the normal course of human life process, protect human health and human capacity for work in different climatic and working conditions [2]. In the process of smart clothing industry development, electronic technologies are to be integrated into clothes, thus creating smart garments equipped with different additional functional properties. Products with integrated electronic systems have a specific structure, i.e. a garment package is provided with an additional electronic layer. The size and characteristics of electronics as well as its placement can affect garment wearing convenience. The interaction between a garment and a human body is important as well; for example, the conductivity of heat and humidity, which affects both user's wearing comfort and the safety of an electronic system, as well as the precise functioning of a smart garment. Thus, when designing smart garments, it is necessary to think about garment microclimate, location of an electronic system, cushioning, etc.

The aim of the paper is to provide the optimum microclimate of garments and wearing comfort in the process of smart garment design. The range of smart garments is rather wide, therefore in this research only smart garments with integrated electronic systems have been analysed.

## II. HUMAN BODY THERMOREGULATION

One of the main functions of a garment is to ensure thermal comfort, which can be achieved by maintaining proper thermal balance, which is related to the thermoregulation processes of a human body, or by using proper clothes [2]. The thermal balance of a body exists when the amount of released heat is equal to the amount of discharged heat [3].

The temperature of separate skin surface areas can vary considerably; it also differs in various places of the body (28°C - 36°C) [4]. Different studies [2, 4] show that the optimal temperature of human body skin surface in the state of rest is 32.10° C – 34.30° C. If the temperature ranges within the limits of 1.5° C – 3° C, a human is a little cold or hot; if the temperature ranges within the limits of more than 4.5° C, a human feels discomfort [5]. The core temperature of a human body is almost unchangeable: 36.50° C. It ranges only within the limits of several tenths of a degree depending on the place of a body and time of the day [4]. Air temperature under a garment is not uniform. Thus, it is rather difficult to determine the air temperature between a human body and a garment because the air temperature under garment should be evaluated differentially taking into consideration human physical activity. Garments create a certain microclimate around the body, and it depends both on the heat state of a human and meteorological conditions of the environment as well as on the characteristics of a garment. Garment microclimate (between human skin and the first layer of clothes) depends on many processes. The factors that influence these processes are shown in Fig. 1.

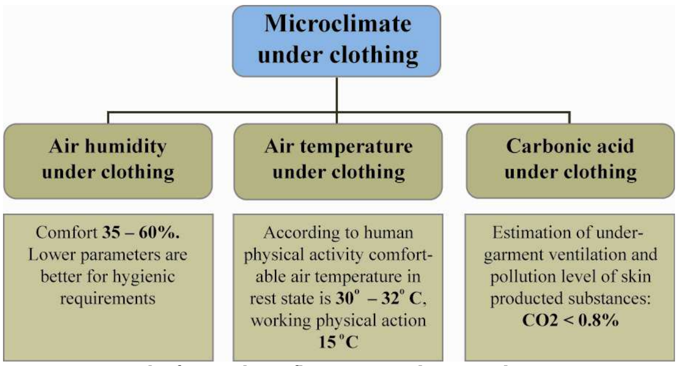


Fig. 1. The factors that influence microclimate under garments

In case of body overheating, when humidity discharge is insufficient, humidity accumulates on the garment, which may cause skin irritation. Excretion of carbonic acid through skin, in its turn, can be increased as a result of active physical work and warm environmental conditions; intensity of ventilation depends on the air permeability of a garment as well as on its construction [2].

## I. INTERACTION BETWEEN A HUMAN AND A GARMENT

A garment system can be characterized as a physiological system interacting with a body. A garment protects a human body from various conditions of the external environment (from cold, heat, fire, toxic substances, etc.). At the same time, a garment can create undesirable heat insulation when it is not needed or block the evaporation of excessive sweat from skin surface.

In normal conditions, without any activity, metabolic heat produced by an ordinary human being is approximately 80 W (like an electric bulb); while under the conditions of high activity, a human can produce more than 1 kW [2]. Certainly, this situation has some positive aspects, for example, the conversion of mechanical energy into electric one. There are some studies conducted on this topic, for example, creation of energy storing nanofibres, which can be woven into textile fabric [6], or garments with a flexible generator converting the energy of wearer's body movements into electricity [7]. However, this research deals with the provision of a stable microclimate. It requires an effective cooling system, and the human physiological system provides this effect. There are several "human-garment" system mechanisms ensuring the maintenance of proper body temperature, the most important of which are as follows:

•Produced metabolic heat should remain on the internal layer of the skin, which can be achieved through effective sweat circulation;

•To cool the body, the skin has to produce a certain amount of sweat;

•Produced sweat (in the form of water or steam) has to get through the garment layers.

The first two factors are uncontrollable (in normal conditions), while the third mechanism can be controlled by using relevant clothes. In order to regulate microclimate, different types of garments can be used:

-Garments with an integrated cooling / heating system;

-Traditional garments of a specific design / made of specific materials.

The garments with an integrated cooling / heating system mostly have an experimental nature; research and developments are made in this area. The given article contains the analysis of traditional garment features, which can be taken into consideration when designing smart garments.

## II. Factors that Influence Thermal Conductivity of Garments

Conduction of heat and humidity steam through textile materials is one of the most important issues in the development of clothes for special purposes. To maintain comfortable skin temperature, a human has to put on or take off clothes depending on the environmental conditions. If clothes could automatically change heat resistance depending on the temperature, they would be able to control the speed of heat production and regulate internal temperature, thus ensuring body comfort [5]. Unfortunately, it does not happen.

Microclimate is very important to the process of heat and humidity conduction from skin to the external environment; therefore, it is necessary to take into account some important parameters that influence this process:

•physical and structural fabric properties;

•morphological properties of fibres;

•structure of filaments [8].

Between a human skin and the external environment there is a layer (or layers) of clothes; therefore, it is important to consider which textile materials to use for the manufacturing of clothes. Different fibre materials have different heat conductivity, which should be taken into consideration when thinking about garment microclimate. Thermal conductivity of different textile materials is shown in Table I [9].

TABLE I

Thermal Conductivity of Different Fibres

| No. | Fibre | Thermal conductivity (mW/m*K) |
|---|---|---|
| 1 | Cotton | 71 |
| 2 | Wool | 54 |
| 3 | Silk | 50 |
| 4 | PVC | 160 |
| 5 | Cellulose acetate | 230 |
| 6 | Nylon | 250 |
| 7 | Polyester | 140 |
| 8 | Polyethylene | 340 |
| 9 | Polypropylene | 120 |
| 10 | Still air | 25 |

Textile materials transfer heat much better than air does, so they are relatively poor insulators. As the table shows, the best insulator is air.

Textile thermal conductivity very much depends on the quantity of air in fabric and to a lesser extent on the fibre composition [5]. Therefore the thermal transfer into textile fabrics affects the degree of porosity, depending both on the fibre arrangement of yarn and on weave and structure of fabric [8].

Therefore to avoid sweating, it is recommended to use breathable fabrics in clothing production. However in this case rain or snow can make clothes wet – moisture spreads through clothing and can reach wearer’s skin. During evaporation of moisture a wearer will feel cold and discomfort. Using the breathable air permeable/waterproof fabric it is possible to avoid such distress – the material passes through the vapour, but does not let water in. This feature can be explained by the size difference of water drop and vapour molecules: the water droplet diameter is 100 µm, while the vapour molecules – 0.0004 µm, so the difference between them is about 250 000 times.

Vapour permeable/waterproof fabrics can be classified in three main categories:

- Coated fabrics: fabrics with waterproof coatings and films, through which fabric pore structure is able to let the air in. There can be micro-porous or hydrophilic material coatings. Most of all, polyurethane is used as a coating material.

- Laminated fabrics (membranes): a micro-porous or hydrophilic membrane is placed between the inner and the outer fabric layers [10]. A 3-layer construction is possible, where a membrane is laminated between the outer base fabric layer and the inner lining layer, or a 2-layer construction, where a membrane is attached to the base fabrics.

- High-density fabrics consist of cotton or synthetic microfilament yarns with a compacted weave structure. Usually yarns are weaved parallel to each other (mostly using oxford weave) with no pores for water to penetrate. When fabric is wetted the cotton fibres swell transversely reducing the size of pores in the fabric and requiring very high pressure to cause penetration. Densely woven fabrics can also be produced from micro-denier synthetic filament yarns. The individual filaments in these yarns are less than 10 microns in diameter, so that fabrics with very small pores can be engineered [11].

The material repels rain and wind, but can transport sweat vapour, which is useful for designing smart clothing – hygienic properties and electronics components are ensured, as well as a wearer is protected from external effects. There are several companies producing these kinds of fabrics, for example, *Gore-Tex, eVent, Polartec, Sympatex, Patagonia* etc. Membranes differ by their properties, so it is necessary to give a clear definition to the intended application. For example, a three-layer membrane *Gore-Tex Pongee* is provided for clothing with high demands, *Gore-Tex XCR* and *Gore-Tex Ural* are particularly air permeable and intended for the most active applications, while a two-layer membrane *Gore-Tex Jura* has a universal use. Such fabrics are traditionally used for ski clothing, raincoats, mountaineering clothing and so on.

Such insulating materials are suitable for smart clothing development. Designing intelligent textile garments with integrated electronic systems require that the electronic components are isolated or at least partially isolated. For example, integrating moisture or temperature sensors into a smart clothing system for measuring the microclimate under clothing, complete insulation of moisture sensor is not possible, otherwise it will not be possible to make precise measurements. Contact of electronic components with the environmental agents (such as humidity) is not desirable both for data detection accuracy and system protection. In this case it would be useful to use the waterproof/breathable material as the base fabrics – it would work as a protective shell for electronics, which protects system components from undesirable contact with the external environmental moisture (rain, snow), as well as ensures hygienic conditions for a human body. Types of membranes should be adjusted according to a smart clothing function – the clothing for emergency workers should be composed of durable membranes, while for daily use in the smart clothing lighter membranes can be used.

## III. Impact of Garment Construction on Thermal Protection Characteristics

Clothing construction and technical parameters of material layers greatly affect the ability to support normal microclimate between clothing and a human body.

Garment type. Clothing heat insulation properties depend on the existing air flow, while human thermal comfort depends on the type of clothing, which regulates the penetration of external air under the clothing. It is possible to assess thermal insulation properties of different types of clothing with a number of physiological hygienic indicators, such as heat flow, skin temperature, temperature under the clothing, heat resistance.

Silhouette (volume). Thermal isolation is affected by garment fit – tight fit clothing compared to the free fit clothing with the same thickness of material package has weaker thermal insulation properties [2].
Smart garment silhouette depends on product type and function. For example, for designing smart clothing with integrated electrodes, which measure heart rate, tight fit silhouette is required. In this case it would be preferable to use elastic material, which has a faster heat and moisture removal feature. These kinds of materials are used for thermal underwear. Constructing other types of smart clothing, which does not require direct contact with the skin, for example – microclimate monitoring jacket, it is advisable to choose free fit silhouette, which will ensure better microclimate maintenance, and electronic elements will be less tangible by contact with the body, as well as the electronic system will be subjected less to friction and other deterioration factors.

Ventilation of material package. Clothing thermal insulation properties depend on the clothing package: clothing material and the number of air layers between different layers of clothing and between the skin and inner layer of garment [2]. Clothing fabric heat loss is affected by heat resistance, but humidity transport – by fabric weave. Heat and moisture distribution is not only the diffusion process; it is also influenced by air movement and ventilation through clothing. During human body motion, the thickness of air layers between the layers of clothing vary depending on physical activities and environmental impact (e.g. sitting, running, wind etc.). By increasing air layer thickness, clothing insulation increases as well. But once the trapped air layer thickness reaches 1 cm, the insulation provided by the trapped air layer will decrease because of the natural convective heat between the skin and garment layer [10].

Sometimes automatic lowering of heat insulation is not sufficient. Body overheating can be reduced by using a suitable garment design and construction, providing additional ventilation into clothing. This can be achieved in several constructive ways:

• Create openings in garments in different parts of the body – neck, wrist, ankle, waist, allowing convection to occur naturally.
• Design free silhouette clothing, ensuring the free flow of air and convection.
• Provide zippers for ventilating proper zones in clothing for specific needs. Example with an integrated zipper in underarm area is shown in Fig.2b
• Do not use waterproof materials wherever it is possible – this will contribute to cooling in the evaporative form [8]. It is more preferable to use breathable waterproof fabric instead.

• Create perforation in zones of intensive sweating for more effective ventilation.

• Place an appropriate fabric inset in the increased sweating areas for better water elimination [8]. Therefore it is important to know human body thermoregulatory processes and the most active sweating areas. Several studies regarding this subject have been done – the heat and moisture release processes of human body are analyzed determining the average amount of sweat excreted in the relevant areas of the human body during physical activity [12]. For example, company *Mountain Hardwear* uses light moisture elimination material (polyester net) in its climbing garment, which is located in body active sweating zones, while heat conservational fabric (merino/polyester knit) is used as a base material [13]. The example is shown in Fig.2a.

a b
Fig. 2. Additional ventilation in clothing.[15;16]

Thickness of the material package. In order to maintain a comfortable under-clothing microclimate, multiple clothing systems are used for special application clothing. Most often these systems are composed of several layers; each has its own features. Generally there are three main types of layers defined: an inner layer, middle layer and outer layer.

- The first layer (inner layer) absorbs sweat, cools the skin and transports moisture [8].
- The second layer (middle layer) insulates body heat, transports moisture to the external layer and dries quickly.
- The third layer (shell) protects against harsh external environment, releases body from moisture, as well as protects against external damage [14].

In smart garments thickness of material package is also influenced by the electronic layer, which depends on several factors:

• Physical characteristics of electronic elements. Depending on the type of electronic components it can have different properties: dimension, weight, flexibility, bulkiness etc.

• Arrangement and distribution of electronic elements in clothing. When choosing the location of electronics in garment, it is necessary to take into account areas of the body – it is important that electronics are away from places with increased friction, bending, etc.

• Technology and type of electronic system insulation. For the insulation of electronic circuits a variety of insulation methods can be used to create a protective coating with different thickness and different flexibility.

• Technology and type of electronic system shock absorption. Different methods and materials can be used for creating shock absorption layers – coating, embroidery, laminating, etc.

• System integration method. Electronic system attaching technology affects the package properties, for example, placing electronics into pockets, circuit printing on fabric, wires and electronic sewing on fabric, circuit embroidery, etc. Some methods are shown in Fig. 3.

Fig. 3. Some electronic system integration methods [17-20]

## IV. Conclusions

Human comfort is affected by both body's internal processes and body-garment interaction. To ensure comfortable feeling, it is important to maintain optimal under-garment microclimate that can be regulated by a variety of clothing construction solutions and the appropriate use of materials, leading to better heat and moisture circulation. The article summarizes a number of recommendations for comfortable smart clothing design, which is the basis for further research of intelligent and interactive prototype developing.

## V. Summary

In the article factors and processes that influence smart clothing wearing comfort have been studied. Human and clothing interaction was considered a physiological system, which simultaneously protects the human body and causes adverse effects to it. Factors, which affect the thermal conductivity through the clothing, have been discussed. Suitable textiles, which protect smart clothing system and the wearer from unwanted contact with the external environment humidity conditions, as well as provide the hygienic conditions for the human body, have been considered. Influence of clothing construction on the properties of the garment heat protection indicators has been analyzed: clothing type, size, materials, ventilation package, the thickness of material package, the electronics layer.


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**Inese Parkova, Ausma Viļumsone. Viedapģērba komforts**

Radot ērtu un kvalitatīvu apģērbu, jāņem vērā ne tikai tērpa estētiskie un funkcionālie aspekti, bet arī jādomā par apģērba dizaina / konstrukcijas un cilvēka ķermeņa mijiedarbību, pārdomājot tā anatomiskās, fizioloģiskās un psiholoģiskās prasības. Attīstoties viedapģērba industrijai, apģērbs tiek izmantots arī kā vietne elektronisko tehnoloģiju integrēšanai, rezultātā radot viedos apģērbus, kas aprīkoti ar dažādām papildus funkcionālajām īpašībām. Šādiem izstrādājumiem ar integrētu elektronikas sistēmu ir specifiska konstrukcija – apģērba paketei tiek pievienota papildus elektronikas kārta.

Rakstā tika izpētīti viedapģērba valkāšanas komfortu ietekmējošie procesi un faktori. Izanalizēti cilvēka ķermeņa termoregulācijas procesi un zemģērba mikroklimatu ietekmējošie parametri. Cilvēka un apģērba mijiedarbība apskatīta kā fizioloģiska sistēma, kas vienlaicīgi gan pasargā cilvēka ķermeni, gan rada nevēlamu ietekmi uz to. Iztirzāti faktori, kas ietekmē siltuma vadāmību cauri apģērbam, piemēram, šķiedru siltuma vadītspēja, gaisa slāņi starp apģērba kārtām, drānu porainības pakāpe, materiāla tvaika caurlaidība un ūdens necaurlaidība utt. Apskatīti piemēroti tekstilmateriāli, kas pasargā viedaģērba sistēmu un valkātāju no nevēlamā kontakta ar ārējās vides mitruma apstākļiem, kā arī nodrošina higiēniskus apstākļus cilvēka ķermenim. Aprakstītas trīs galvenās tvaiku caurlaidīgo/ūdensnecaurlaidīgo drānu kategorijas, kā arī apkopoti vairāki komerciāli pieejamie šāda veida materiāli. Izanalizēta apģērba konstrukcijas ietekme uz izstrādājuma siltumaizsardzības īpašību rādītājiem: apģērba veids, apjoms, materiālu paketes ventilējamība, materiālu paketes biezums. Tika apskatītas arī elektronikas kārtas īpatnības un faktori, kas ietekmē viedapģērbu materiālu paketes biezumu: elektronikas elementu īpašības, izvietojums un sadalījums apģērbā, sistēmas izolācijas un amortizācijas veids un tehnoloģijas, sistēmas integrēšanas veids. Rakstā apkopotie ieteikumi komfortabla viedapģērba projektēšanai ir pamats turpmākajiem pētījumiem viedo un interaktīvo prototipu izstrādē.

**Инесе Паркова, Аусма Вилюмсоне. Комфорт умной одежды**.

Создавая комфортную и высококачественную одежду, необходимо учесть не только эстетические и функциональные аспекты одежды, но и думать о взаимодействии дизайна / конструкции одежды и человеческого тела, продумывая анатомические, физиологические и психологические потребности. С развитием индустрии интеллектуальной одежды, одежда используется также в качестве места для интеграции электронных технологий, в результате чего интеллектуальная одежда оснащена различными дополнительными функциональными свойствами. У таких изделий с интегрированной системой электроники специфический дизайн – к пакету одежды добавляется дополнительный слой электроники.

В статье были исследованы процессы и факторы, влияющие на комфорт ношения интеллектуальной одежды. Проанализированы процессы терморегуляции организма человека и параметры, влияющие на микроклимат под одеждой. Взаимодействие человека и одежды рассмотрена как физиологическая система, которая одновременно защищает организм человека, так и вызывать неблагоприятные последствия для него. Были обсуждены факторы, которые влияют на теплопроводность через одежду, такие как теплопроводность волокон, слои воздуха между слоями одежды, пористость ткани, паропроницаемость и влагонепроницаемость материала и т.д. Рассмотрены подходящие ткани, которые защищают систему умной одежды и ее владельца от нежелательных контактов с внешними условиями влажности окружающей среды, а также обеспечивают гигиенические условия для человеческого тела. Описаны три главные категории паропроницаемых / влагонепроницаемых тканей, а также обобщены различные коммерчески доступные материалы данного вида. Проанализировано влияние конструкции одежды на свойства тепловых показателей изделия: тип одежды, обьём, вентиляция пакета материалов, толщина пакета материалов. Также рассмотрены характеристики и факторы слоя электроники, влияющие на толщину пакета материалов интеллектуальной одежды: характеристика электронных компонентов, местоположение и распределение в одежде, тип и технологии изоляции и амортизации, тип интеграции системы. Приведенные в статье рекомендации для проектирования интеллектуальной одежды являются основой для дальнейших исследований разработки прототипов умной и интерактивной одежды.