Study on the behaviour and comfort of reusable knitting suits of wool blends in the context of the Covid 19 pandemic

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Abstract. Nowadays, humanity is facing serious challenges due to the disruption of the COVID-19 pandemic, affecting dramatically our healthcare system along with the economic structure, social and cultural life [1]. Healthcare personnel treating patients with infections like Covid-19 are exposed themselves to infection. Therefore, it is compulsory to be protected from contaminated body fluids using personal protective equipment (PPE) [2].

1. Introduction

Nowadays, humanity is facing serious challenges due to the disruption of the Covid-19 pandemic, affecting dramatically our healthcare system along with the economic structure, social and cultural life [1]. Healthcare personnel treating patients with infections like Covid-19 are exposed themselves to infection. Thus, it is compulsory to be protected from contaminated body fluids using personal protective equipment (PPE) [2].
But this equipment proved to be uncomfortable to the wearer in extended use since it consists of synthetic fibers. The current application of textiles in the medical field and past pandemics are well known. Presently, there is a major concern in evolving in the forthcoming future protective clothing based on nonwoven micro-and nanoporous materials. The main benefits of these new materials relay in their, breathability, lightweight, lower price and comfort [1].

Under these circumstances, we take into account the possibility to develop a reusable suit to be worn by healthcare staff in the Covid sections under the full-body protective clothing aiming to improve their comfort and safety. Why is comfort so important? Because better comfort impedes stress and tiredness.

The main objective of the study envisages whether a simple protective cloth composed of a blend of natural fibres wool and silk (95% wool and 5% silk) is appropriate to enhance both ergonomic and physiological comfort. The study was developed by an interdisciplinary team, formed by researchers and engineers from the Textile Industry field, accounting field and healthcare staff from the Covid hospitals.

As a complex issue, ergonomic comfort is considered how well the clothing suits, if it allows the wearer to perform easily all the necessary movements. It is quite simple to estimate by trying the garment on. Physiological comfort involves skin sensory comfort and thermo-physiological comfort [3].

Thermo-physiological comfort refers to a pleasant thermal and humid condition involving both thermo-regulating and moisture-regulating capacity in addition to the thermal insulation capacity of the clothing. All these abilities are related to the environmental and working conditions. Furthermore, thermo-physiological comfort is influenced by the fabric composition and structure and garment construction [4-6].

Since the style and cut of the two-piece ensembles conceived by our team do not restrict movements and do not exert any constraints upon the body, the study investigated the parameters representative for their thermo-physiological comfort. Because people using similar clothes, in identical physical ambiance may perceive various comfort degrees, our study was completed with the results of a survey regarding the subjective perception of the comfort level of about 51 volunteers from medical staff.

2. Material and Methods
Within this experimental part, we focused firstly on the analysis of some dimensional characteristics like mass per square meter, porosity, thickness followed by comfort characteristics of knitted fabrics designed to be used for the suits.

Accordingly, the test methods accomplished comprise measurements for hydrophilic properties, air and water vapour permeability [7], thermal conductivity and dimensional stability to repetitive washing. Since we refer to a reusable ensemble that will be subjected to several washing processes, dimensional stability is also an important aspect, because wool fibre is a precious natural material very sensitive to shrinking.

2.1. Materials
Fabric subjected to testing is a blend of wool/silk 95/5% knitted fabric, supplied by SILVANIA WORSTED SPINNING SRL. Why a blend of natural fibers?

Because wool continues to be a unique apparel fibre with a remarkable array of technical features. These properties refer to softness, warmth and coolness, breathability, moisture absorption and buffering resilience, odour absorption, softness, stain and flame resistance, elasticity, biodegradability and recyclability. Due to these excellent attributes, wool can be employed either for a worsted suit or knitted outerwear and/or for technical applications [8,9].

Besides, the adaptability of wool has been revealed by several leading-edge clothing products designed for the sportswear area, including outerwear, mid-layer, and underwear garments, that require superior moisture management [10,11].

Further, the presence of silk in the blend contributes to enhanced softness.
2.2. Methods

2.2.1. Specific mass. The specific mass is defined as the mass, in grams, of a unit of area (m²) of the material. The determinations were performed according to D 3776/D3776M – 09a “Standard test methods for mass per unit area (weight) of fabric” on circular test specimens taken from different parts of the knitted fabric using the GSM cutter. The values given in the table are the average of 10 determinations.

2.2.2. Fabric density. Assisted by a counting glass, the stitch density of the knitted fabric, expressed in wales and course per centimeter, was measured, according to ASTM D 3887-96(2008)"Standard Specification for Tolerances for Knitted Fabrics"

2.2.3. Porosity. Porosity is a parameter with a significant influence on both the absorption and desorption of textile materials. An increase in porosity leads to enhanced vapour permeability and permeability to air [7]. The porosity of the analysed sample Pz[%] was determined by the pycnometric method.

2.2.4. Fabric thickness. The thickness of the knitted fabric was assessed using a textile micrometer model DM 100.

2.2.5. Hydrophilic properties. The evaluation of the hydrophilic properties of the analysed knitted fabric was carried out according to the AATTCC Test method standard 79-2007. By this method, a drop of water is delivered from a burette to the surface of the material subjected to analyses. The time required for the water absorption represents the wetting time.

2.2.6. Air permeability. The air permeability measurement was accomplished according to the ASTM D 737-04), Standard Test Method for Air Permeability of Textile Fabrics. For this purpose, the ATL2 Metrimpex apparatus was used. The working parameter was set for a difference in air pressure Δp =5mCol water and a temperature of T=20 °C. Δp – represents the pressure difference between the two sides of the knitted fabric and T the average air temperature adopted for each season and used for calculations. The recorded values of the air permeability (P_a) were expressed in [m³/min m²].

Additionally, air permeability index (i) and airflow passing resistance Rpa [mm m² h/kg] have been considered for the assessment. The air permeability index (i) [kg/m²-h] has been determined with the equation (1):

\[ i = 60 \cdot Pa \cdot \gamma \left( \frac{kg}{m^2 \cdot h} \right) \] (1)

where: \( \gamma \) — represent the air density [kg/m³]; 
\( Pa \) - air permeability corresponding to the knitted fabric [m³/min·m²].

The air density shall be calculated with the equation (2):

\[ \gamma = \frac{\gamma_0}{1 + \frac{t}{273}} \] (2)

where: \( \gamma_0 \) — air density at temperature 0 °C [\( \gamma_0=1.293 \) kg/m³]; 
\( t \) - the temperature of the air passing through the textile material (temperature of 20 °C).
2.2.7. **Water vapour permeability.** Measurements of water vapour permeability were performed using the upright cup method (Water Vapour Permeability - ASTM E 96 Method B). The samples were positioned and sealed above a cup filled with distilled water at a depth of ¾ from the height of the cup. After that, the samples were placed in a standard atmosphere (23 ± 1 °C and RH 50 ± 2 %) with ventilation in a Pol-Eko-Aparatura oven. The test was carried out for 6 hours. The gravimetric method was used to evaluate the change in mass every two hours. The specimens were weighed on a sensitive Kern balance, model ABT220-4M and the difference between the mass at 2, 4 and 6 hours of vapour exposure and initial mass represents the ability of the knitted fabric to transfer perspiration. Vapour permeability has been also evaluated through water vapour transmission coefficient (WVT) μ[g/m²-h].

2.2.8. **Thermal conductivity.** The thermal insulation properties of the knitted fabric were assessed via the coefficient of thermal conductivity λ[kcal/m·h·°C] using the λ Tex Tester, with a sintered copper plate, on the principle of the skin model. Using the analytical method, the indirect indicator heat transfer resistance Rt [m²·h·°C/kcal] has been calculated for a complete assessment of the comfort properties.

2.2.9. **Dimensional stability after home laundering.** The dimensional stability of the suits manufactured from knitted fabric to home laundering was assessed taking into consideration the method describes in AATCC Test Method 150-2003 Dimensional Changes of Garments after Home Laundering. The washing was carried out on the automatic washing machine Zanussi HydroLine, model ZWF 1438. Laundering of textiles is a process designed to remove dirt and/or stain by washing with an aqueous detergent solution. The treatment operation normally includes washing, rinsing, and drying of the material. Dimensional stability refers to the ability of fabrics or knitted fabrics, garments (specimens) to keep the shape and dimensions following domestic maintenance procedures (washing, cleaning, ironing). The change is usually indicated as a percentage of the initial dimension of the textile specimen. From the point of view of the dimensional stability of the knitted fabric, the first washing is of particular importance. Thus, factors like washing temperature, washing agents, treatment duration, and mechanical action exert an important influence upon the washing process and dimensional stability. Accordingly, for washing the knitted fabric suit of 95% wool / 5% silk, an appropriate program designed for wool clothes was chosen. The washing conditions were as follows: 50 ml of commercial detergent, washing temperature 30 °C, 500 rpm centrifugation, and treatment time 51 minutes. After the washing procedure, the suits have been dried free at ambient temperature.

2.2.10. **Softening.** Before the testing, the suits were subjected to treatment with a commercial softener for a soft handle. Each person from the healthcare system involved in the study received a suite and a set of information regarding the chemical composition of the textile material, washing guidance and its use.

3. **Results and discussion**

3.1. **Specific mass (grams per square meter), density and thickness of the knitted fabrics**

The characteristics of the knitted fabric assessed by standard methods are comprised in table 1.

| Table 1. The specific mass, fabric density, and thickness of wool-knitted fabric blend with silk. |
|-----------------------------------------------|
| Knitted fabric 95% wool + 5% silk |
| Mass/m² [g/m²] | 155.50 |
| Density | Courses/centimetre (cpc) | 12 |
| | Wales/centimetre (wpc) | 20 |
| Thickness [mm] | 0.76 |
3.2. Evaluation of dimensional stability after home laundering
To better highlight dimensional changes after household washing, 10 washing/drying cycles have been accomplished with measurements taken after each washing cycle. Since the suit should be worn as a mid-layer garment being in contact with the skin, washing after each wear is mandatory. We selected a higher number of washing/drying cycles than the one specified in the standard for the following reasons: the suit is made of knitted fabric that is susceptible to deformation and on the other hand the wool fiber has an accentuated tendency to shrink by repeated washing.

The following references were used to accomplish the measurements:
- Length of trousers, front rise and back rise;
- Sleeve lengths of the blouse (on the back from the shoulder to the bottom hem);
- The body length of the blouse;
- Width at the chest of the blouse, both front, and backside.

Figure 1 and figure 2 illustrate the dimensional changes in the length of the pant after each washing cycle (Wc). The measurements were taken both in the wet state of the material immediately after washing and after drying in a free state at ambient temperature.

![Figure 1](image1.png)

**Figure 1.** The length of the wet and dried trousers after each cycle of washing/drying.

![Figure 2](image2.png)

**Figure 2.** Shrinkage of trousers length after each wash/dry cycle.
The measurement reveals a change in the length of the trousers after the first wash, this being reduced from 102 cm by 1.3 cm, meaning a shrinkage of 1.27% from the initial length. An increase of the shrinkage was also noticed after the second wash cycle to 1.96%. After this, the length is maintained constant until the washing cycle 9 characterized by shrinkage of 2.94%.

The same value of 2.94% was obtained after the 10th wash cycle. About the dimensional change of the pant in a wet state, an unstable behavior is observed with shrinkage of the material up to the washing cycle 6, after which the material elongation occurs at cycle 7 and 8, followed by shrinkage after cycle 9 and again an elongation after washing cycle 10.

The dimensional changes recorded for the blouse following each washing cycle are presented in figures 3, 4, 5, 6 and 7. Figures 3 and 4 show changes in the sleeve of the blouse after 10 washing cycles.

Figure 3. Length of the blouse sleeves in wet and dry condition after each washing/drying cycle.

Figure 4. The blouse sleeve shrinkage in length after each washing/drying cycle.
Concerning the changes in the sleeve of the blouse with an initial length of 50.7 cm, a shortening of 0.5 cm was observed after the first wash, corresponding to shrinkage of 0.99%. The shrinkage increased to 1.97% (1 cm) after the second wash and to 2.37% (1.2 cm) after the third wash. This value went on constant for the 4-8 washing cycles after which on the 9 and 10 cycles the shrinkage increased to 3.35% (1.7 cm). Dimensional changes in the wet sleeve show the same variable behavior as the pants, observing several contractions alternated with elongations.

Figures 5 and 6 illustrate the changes in the length of the blouse after each washing cycle.

From the presented figures, it can be observed that the length of the blue has been kept at the same value as the initial length until after the second washing cycle when it has suddenly decreased by 0.5 cm (1.32% shrinkage).

From washing cycle 3 to 10 no further change has occurred. As regards the wet length of the blouse, a more stable behavior is observed compared to that of the sleeve or pants, with only 2 slight elongations after washing cycle 7 and washing cycle 10. Finally, analysis of the dimensional stability of the blouse after repeated washings considered the assessment of the width. The values obtained after each washing cycle are given in figure 7.
Figure 7. The width of the wet and dry blouse after each washing/drying cycle.

Considering figures 7 it can be observed that the width of the blue has not changed from the initial width (46.5 cm), with the contraction being 0%. Repeated washings have led to an increase in density in wales direction and compactness of the fabric, thus increasing the number of yarn-to-yarn contact points and the number of contact surfaces between the yarns, all leading to dimensional changes.

The length of the pants was within ±2% of the acceptable limits only up to the 9th washing cycle. As regards the blouse, the length of the sleeve exceeds the allowed limit after washing cycle 3, due to the shrinkage of 2.37%. For the length of the blouse, the shrinkage does not exceed 1.32% even after the 10th washing cycle. The width of the blouse was constant after all 10 washing cycles.

After each washing cycle, the mass change of the suit was also followed. From figure 8, a mass decrease of 0.83% can be observed after the first wash, reaching a maximum of 1.54% after the 4th wash and then begins to rise above the initial mass after the seventh wash. This can be ascribed to the fact that after the first washing a removal of impurities and other substances present on the material occurred.

Besides, the increase in mass from washing 8 may be attributed to several successive washing steps that have led to fiber swelling and improvement of the material's hydrophilic features, which makes it easier to regain the humidity from the environment.

Figure 8. Weight of the suit after each washing/drying cycle.
3.3. Hydrophilic properties
Clothing in general, but particularly the first layer that comes into contact with the skin, should properly dampness the moisture in excess from the undergarment area. This requires that materials designed for the first layer of clothing are hydrophilic, being capable of absorbing or adsorbing moisture and ensuring its migration into or onto the surface of the material.

Average values of five determinations accomplished on different areas of the material have been considered. The results reveal that the knitted fabric in its original state did not absorb any water at all, but its wettability increased with each wash, attaining a wetting time about 30 seconds after the washing cycle 5. This wetting time could be noticed also after the 10th wash cycle.

For a material to be considered hydrophilic, the wetting time should be approximately 10 seconds. In the present case, no proper hydrophilic feature has been obtained for the analyzed knitted sample. Since the wool and silk fibers are very hygroscopic, the explanation for this result may be ascribed to former treatments applied to the material which generate its hydrophobic behaviour.

3.4. Air permeability
Air permeability is an influential determinant in the performance of textile material designed for clothing and technical application. Factors affecting the air permeability include the yarn properties, fabric structure (knitted, woven, nonwoven) and properties such as thickness, density, porosity, together with finishing treatments.

To evaluate the air permeability of the knitted fabric we choose as reference a 100% cotton knitted fabric with similar characteristics designed for an undergarment. According to the values from table2, our suit presents comparable air permeability with reference (60.29 m³/min m²) [12].

| Porosity [%] | Air permeability [m³/min m²] | Air permeability index [kg/m²h] | Airflow passing resistance [mm² m² h⁻¹/kg] |
|--------------|-----------------------------|---------------------------------|------------------------------------------|
| 89           | 60.68                       | 4386.46                         | 0.00016                                  |
| 83.33        | 58.71                       | 4227.12                         | 0.00012                                  |

For a comprehensive evaluation of the air permeability features, another relevant parameter was airflow passing resistance, calculated for undergarments (consisting of 1 layer) by using the values for fabric thickness and the calculated air permeability index. The lower the airflow passing resistance is the better the comfort properties of the analysed suit are.

3.5. Water vapour permeability
Water vapour permeability characteristic is one of the crucial factors in determining clothing comfort as it represents the ability to transfer perspiration. To assess the transfer of water vapour by diffusion, the permeability of vapours (Pv) has been used as a direct indicator. The recorded values are depicted in table 3, representing the mass change at every 2 hours of the tested samples. The increasing of the exposure time leads to a more significant mass difference compared to the initial one.

The results suggest the blend’s ability to transfer humidity from the body to the outer layer of the suit.

| Samples of single-layer knitted fabric | Pv - 2h [g] | Pv - 4h [g] | Pv - 6h [g] |
|--------------------------------------|------------|------------|------------|
| P1                                   | 0.286      | 0.593      | 0.286      |
| P2                                   | 0.067      | 0.796      | 0.067      |
Figure 9 presents the water vapour transmission (WVT) coefficient ($\mu$) at 2, 4 and 6 hours for the single-layer knitted fabric samples.

![Figure 9](image)

**Figure 9.** Evolution of water vapour transmission coefficient.

A significant increase in the water vapour transmission (WVT) coefficient ($\sim 4.7$) was noticed after 2 hours for the knitted fabric. After four hours, a further increase was observed, but less pronounced, the WVT coefficient being 6.2. From 4 to 6 hours according to the WVT coefficient (6.4) the water vapour transmission was slower. Even so, after 6 hours the material still can transfer moisture.

### 3.6. Thermal conductivity

The thermal isolation of the human body by clothing intends to establish a thermal regime that allows the development of various processes of the body, inside the comfort limits. Besides other functions, the garment competes in establishing a thermal balance among the produced and released quantity of heat. The heat transfer by conduction takes place only in case of a difference between the body temperature and the outside temperature [13].

The defining parameters for heat transfer of the knitted fabric are depicted in table 4. These values reveal a good thermal conductivity with low heat transfer resistance according to the expected values of the end-use of the conceived ensemble. Besides, the heat transfer resistance is even lower than that of the reference (0.0537 m$^2$h°C/kcal) [12].

**Table 4.** Thermal conductivity of the knitted fabric.

| Samples | Thermal conductivity-$\lambda$ [kcal/m$h$°C] | Heat transfer resistance-$R_t$ [m$^2$h°C/kcal] |
|---------|---------------------------------------------|-----------------------------------------------|
| 1       | 0.0414                                      | 0.01787                                       |
| 2       | 0.0378                                      | 0.02063                                       |

### 3.7. The comfort perception via survey

Conclusions on the wearing comfort of the knitting suits were formulated based on a questionnaire. This questionnaire was answered by 51 medical staff, with an average age between 47 and 48 years (13 men and 38 women). Over 90% of respondents appreciated the suit, consisting of a blouse and pants, as a comfortable one.

At the request of explaining the choice made regarding the comfort conferred by the suit, the vast majority were satisfied with the comfort conferred. Only a few responded that it irritates the skin and gives a warm feeling. Almost 90% of the respondents appreciated that this suit ensured good
thermophysiological comfort during all the wearing. More than 90% of the respondents appreciated that from a sensory point of view, the suit gave the feeling of soft/velvety/silky.

Regarding the dimensional changes following washing treatments, at home, almost 40% of respondents reported dimensional changes.

4. Conclusions
Within the study, we developed a reusable suit composed of a blend of natural fibres (wool/silk 95/5%) addressed to the healthcare staff in the Covid sections. This suit should be worn under the full-body protective clothing that proved to be uncomfortable, intending to improve their termo-physiological comfort. The accomplished investigation methods envisaged whether our suit fulfills or not the termo-physiological comfort properties. The results of the study confirm the fact that the conceived suit can ensure appropriate termo-physiological comfort to the healthcare personnel.

Besides, the results of the research are consistent with the perception of the medical personnel involved in the study via the survey.

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Acknowledgements
The study was carried out under a research contract funded by Silvania Worsted Spinning S.R.L from Simleu Silvaniei, Salaj, Romania.