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ملابس العمل المخصصة للبيئة شديدة الحرارة

Special Workwear for Extreme Hot Conditions

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الملخص

تتطلب ملابس العمل المخصصة للبيئة شديدة الحرارة والرطوبة منسوجات تقنية ذات خصائص وظيفية. بشكل عام، يتم تصنيع هذه الملابس لتدوم طويلاً وتتمتع بخصائص ميكانيكية ممتازة، ولكن الراحة على وجه التحديد لا يتم تجاهل خصائص الراحة الفسيولوجية الحرارية. في هذا البحث، تم اختيار ملابس العمل الأكثر شيوعًا (القميص والبنطلون) المستخدمة في منطقة الشرق الأوسط مع الحرارة الشديدة والبيئة الرطبة واختبارها من حيث الخصائص الميكانيكية والراحة. لاحقًا، تم تصنيع 3 قمصان وسراويل أخرى بتصميم مماثل ولكن بمواد نسيجية أكثر وظيفية وعامل اقتصادي أفضل. أظهرت النتائج أن بنطلون الدنيم يظهر خصائص راحة ممتازة مع خصائص ميكانيكية مماثلة، في حين أظهرت القمصان المصنوعة من البوليستر سريع الجفاف إدارة أفضل للرطوبة وسلوك الراحة. ويفيد البحث في تحديد الملابس الجديدة للعاملين في البيئات الحارة.

Abstract

Workwear for extreme hot and humid environment requires technical textiles with functional properties. Generally, these garments are designed to be durable and has excellent mechanical properties. However, comfort, specifically the thermo-physiological properties, sometimes are neglected.
In this research, the most common outwear garment (shirt and pant) used in the Middle Eastern region, with extreme heat and humid environment, were selected and tested for mechanical and comfort properties. Subsequently three new sets of outerwear were made with a similar design but with more functional textile materials and better economical factor. The results show that denim pant shows excellent comfort properties with similar mechanical properties whereas the shirts from quick dry Polyester showed better moisture management properties. The research is useful in determining the new outwear for the workers operating in hot environments.

Introduction

Textile materials are at the forefront of personal protective equipment (PPE), which includes a wide spectrum of modern protective apparel such as coats, pants, and vests, as well as other body armor goods such as helmets, masks, aprons, gloves, socks, and shoes. There has been a constant and substantial demand for these protective textile items in recent decades, driven by a growing emphasis on eliminating industrial dangers and assuring the health, safety, and protection of the workforce [1-3]. Dynamic, variables such as the ongoing modification and creation of legislation, governmental policies, standards, and industrial/organizational rules drive this sustained expansion. These initiatives have prompted businesses and individuals to proactively implement accountability measures and equipment to prevent workplace hazards and accidents. Different PPE and clothes are gradually becoming available. A standard and norm in the industry [3-5]. This need results in massive use of protective materials and a surge in protective textile product innovation. On the one hand, the high demand for protective clothing drives the development of high-performance new textile materials and relevant technology; on the other hand, the rapid development of new technologies in emerging interdisciplinary fields such as nanotechnology and biomimetics drives the advancement of the protective clothing market [4-5].

In the relentless embrace of scorching temperatures, individuals toiling in extreme heat conditions face a formidable challenge how to stay cool and comfortable while carrying out the demanding tasks [3-6]. As the mercury soars, the need for innovation solution becomes paramount, giving rise to a pivotal transformation in worker design. The evolution of clothing for workers in extreme heat conditions is not merely a matter

of fashion, it's is a crucial aspect of ensuring health, productivity and overall well-being.

In this article, we delve into the cutting-edge realm of workwear engineered to combat the relentless onslaught of extreme heat. From advanced fabric technologies to ergonomic design principles, a new era of occupational clothing is emerging to empower workers, enabling them to navigate their professional responsibilities with heightened efficiency and comfort [6,7].

Composites fabrics are a cutting-edge technological advancement in the field of material science. They are a result of the combined action of two or more materials to produce a synergistic effect. Such textiles, which are specially designed for survival and protection, are essential for providing increased performance and durability within an extensive variety of applications.

The necessity for sophisticated protection gear is becoming more and more apparent as companies develop, particularly in settings with harsh conditions like severe heat. One noteworthy use of composite materials is in production of new clothes for laborers who work in intense heat. These cutting-edge materials combine thermal insulation qualities to protect people from the damaging effects of high temperatures, guaranteeing their comfort and safety in strenuous work setting [8-10]. The personalized approach to producing clothes for intense heat takes advantage of the many features of composite materials, such as their capacity to provide thermal insulation, abrasion resistance, and breathability. Composite fabrics, designed with a combination of critical features and components like as thermal resistance and better breathability, provide a solution to the issues faced by workers in intense heat. This not only improves their safety but also satisfies the requirement for comfort throughout long hours of work,

demonstrating the versatility of composite textiles to various environmental needs. This introduction thus sets the stage of an investigation into how composite textiles help to the development of cutting-edge clothing that assures the well-being and performance of workers exposed to intense heat.

Literature review

A review of historical workwear innovation underscores the continual pursuit of adapting to challenging environments. Studies emphasize the integration of advanced materials and technologies to enhance thermal comfort, durability and safety. However, the unique demands posed by extreme heat conditions have given rise to a new wave of specialized workwear solution, prompting the need for tailored approaches.

The literature emphasizes the significance of flame-resistant textiles, materials combination, thermal resistance testing methods, moisture management technologies, and tensile strength concerning workwear innovation. Studies underscore the delicate balance needed between comfort and performance, considering factors such as fabric composition, construction methods, and the specific demands of the work environment.

The main aim of this innovative study was to create concentrated thermally resistant clothing for construction workers working in hot and humid conditions. The researchers dug into the complexities of fabric properties related to heat and moisture transport, UV protection, and the nuanced ergonomic considerations of mobility, convenience, and safety after following De Jonge's strategic clothing design process.

Surveys were conducted at three local construction sites to establish the research foundation, which aligned seamlessly with observed conditions and essential task

requirements. The research yielded different specifications, which resulted in the identification and testing of 30 commercially available fabrics. As fabric testing data and design considerations were seamlessly integrated into the advanced S-smart system, predicting the thermal functional performance of the envisioned clothing, a unique approach appeared. The end result of this inventive journey was the creation and testing of a prototype for a cutting-edge uniform. Comprehensive measurements and assessments revealed promising results, indicating that this Cutting edge uniform, with superior fabric heat and moisture transport properties and a thoughtfully implemented loose-fitting design, not only had the potential to alleviate heat stress among workers but also significantly improve their comfort levels and overall work performance [10-13]

The current state of construction workers' clothing in South Korea was thoroughly examined in this study, which classified it based on the construction site and job positions. A survey was carried out with 102 workers in construction, including managers and laborers. In addition, comprehensive interviews with three construction workers were carried out to assess their working positions and identify discomfort in their workwear. Workers in the construction industry, which is defined by seasonal changes and possible risks, expressed concerns about being exposed to heat on their faces in summer as well as chilly hands in the winter. The study discovered that, while managers wore company-provided workwear, workers did not and instead purchase their own from local markets. When making personal purchases, supervisors tended to buy workwear from outdoor stores. Both workers and managers expressed a desire for new functional workwear designs. In-depth interviews revealed specific discomfort areas linked to primary work postures, such as the back, upper arms, thighs,

knees, and hips. Respondents emphasized the importance of having pockets that are the right size and position for their job. Based on these results, the study developed practical demands for construction workwear, shining light on the aspects that should be emphasized when designing clothing for construction workers [12–15]

The necessity for high-level safeguarding within the realm of personal protective clothing (PPC) poses a formidable challenge to the facilitation of heat exchange through sweat evaporation, especially in hot environments. This constraint not only causes significant physiological strain, but it also raises concerns about the possibility of worker exhaustion. In response to these challenges, recent advancements in heat transfer algorithms have emerged, incorporating factors such as pumping and wind effects, resulting in an important boost in thermal stress prediction.

These algorithmic advancements enable practical adjustments to measures of thermal insulation and evaporative resistance within specific clothing ensembles, in line with established international standards for thermal environment assessment. Significant factors, such as directional radiation and the impact of wetting on clothing layers, were thoroughly researched in a recent EU research project, highlighting the multifaceted nature of considerations in this domain. Furthermore, ongoing efforts in the development of advanced thermal manikins and measurement procedures promise to enhance predictive models' accuracy and applicability. However, as with any methodology, the results derived from these advancements must be validated through realistic wear trials to ensure their practical relevance and accuracy in real-world scenarios (E, Year). This synthesis of research findings highlights the ongoing commitment to improving our understanding and application of thermal dynamics in

personal protective clothing, all within the dynamic framework of evolving international thermal environment assessment standards [13–15]

The dynamic interplay between wind, thermal insulation, and water vapor permeability in single-layered, ready-made garments is examined in this study, which employs a "sweating arm" for measurements. The study's goal is to determine the effect of changing climatic conditions on clothing properties, with a focus on the potential risk of hypothermia. The results of this study show an apparent connection between permeability to air and either thermal or water vapor resistances, providing valuable insight into the complicated properties of various fabrics. The study does warn, however, that this relationship may not be universal, especially when Wind-tight materials are involved. Furthermore, the study reveals non-linear correlations between water vapor resistances measured with and without air layers, highlighting the complexities of clothing performance. These findings contribute to a better understanding of how clothing reacts to changing environmental conditions [14,15]

The text under consideration introduces the concept of an adaptive approach to assessing heat strain, highlighting human action dynamic role in reacting to microclimates, clothing, and environmental conditions. It challenges traditional methods, which frequently overlook the active measures people use to reduce heat stress, such as adjusting work rates, changing clothing, and changing their posture. The adaptive approach advocates for a more comprehensive and context-aware assessment, emphasizing the significance of individuals' ability to behave appropriately in specific environments. The text also applies to the effects of protective clothing, focusing on the dominant role of human beings in thermoregulation, comfort, performance, and

survival. This novel viewpoint adds to the literature by addressing the limitations of current methodologies and paving the way for future research [15-17]

Materials and Methods

The research follows the experimental method

The experimental works includes 1 pants and 1 shirt which is used by the workers in the middle-east region. For the pants 4 multiple variants of materials are used to stitch the same size and design as the original to compare the functional properties.

For the shirt, three new materials are bought to design and stitch shirts to compare the functional properties with the original shirt.

Laboratory tests were conducted in Department of Clothing, Technical University of Liberec, Czech Republic.

The sample 1 of shirt and pant, which is the original samples used by workers is bought from Saudi Arabia and properties are listed in table 1.

Table 1. Original shirt and pants properties

Original samples	Fabric information	Size	Thickness [mm]	Weight per unit area GSM [g/m2]
Shirt 1	100% Rib- Polyester knitted	M	0.65	170
Paint 1	100% Polyester- Woven plain	M	1.2	330

For the pants following materials are bought according to the functional properties and usage in the workwear or technical clothing.

Table 2 shows the details of the pants materials

Pants	Fabric information- Trade name	Fiber contents	Colour	Thickness [mm]	Weight per unit area GSM [g/m2]
1-Original	PES-work-wear	100% Polyester- Woven plain	Grey	1.2	330
2	Proban	100% Cotton Woven plain	Blue	1.35	325

Pants	Fabric information- Trade name	Fiber contents	Colour	Thickness [mm]	Weight per unit area GSM [g/m2]
3	Denim	100% Cotton 2/1 Twill	Dark Blue	0.98	300
4	Workwear	50%Cotton / 50%PES plain	Green	1.44	340
5	Fire man	60%Cotton /40%PES Plain weave	Red	1.59	335

The materials are selected according to the functional usage in the workwear clothing. The garments are designed and stitched same way and size as the original sample

The prepared garments are shows in figure 1.

Fig 1: Pant Samples (Researchers Design)

- Main samples (Polyester): Serving as a foundation benchmark, the original

workwear pant, crafted from robust polyester woven fabric, establishes a baseline for comparative analyses despite its strength, initial assessment's reveal potential discomfort.

- Proban blue (cotton): The Proban blue pant introduces a flame-resistant element through a complex chemical process. The cotton base ensures safety without compromising comfort, potentially marking a breakthrough in dire-resistant workwear.
- Denim cotton (dark blue): Leveraging the durability of denim, the dark blue workwear pant offers cost-effective performance, making it a promising option for tasks requiring abrasion resistance.
- Cotton/PES mix green: Balancing mechanical performance and comfort, the cotton/polyester mix workwear pant caters to workers seeking a combination of strength and ease.
- Red work wear (Firefighter): Tailored for firefighters, the red workwear pant incorporates classical firefighter fabric, providing necessary protection for scenario's involving a 1st degree fire.

Similarly, the shirt material is bought according to functional properties and the properties are shown in table 3

Table 3. Shirt properties

Shirts	Market names			Figure 1.PNG
1	Original	100% Rib- Polyes-ter knitted	0.65	170
2	Original+ Cotton back	PES+Cotton (as back fabric)	0.65	170(Polyester) 185 (Cotton)
3	White jersey	PES- Elastane (90/10)	0.59	165

Shirts	Market names			Figure 1.PNG
4	Quick dry strong	PES (95% recy-cles, 5% elastane) interlock	0.68	179
5	White functional	PES knit 100%	0.61	172
6	Pink jersey	PES 100%	0.64	192
Fabric of under arm				
7	Blue/white	face70% viscous, 30Acrylic. Reverse PP100%	0.85	
8	Pink/white	35% PP, 32 Viscous, 32.5 Cotton	0.91	185
9	Navy Blue/white	35% PP, 32 Viscous, 32.5 Cotton	0.91	180

Followings are the pictures of the shirts made for this experiment work. The design is kept similar to the original one to finally compare the results.

Sample (1+2) | Sample 3 with 9 (under arm) | Sample 5 with 7 (under arm) | Sample 4 with 8 (under arm)

Fig 2: Shirt Samples (Researchers Design)

Results

All the testing results of pants and shirts are measured using standards ISO methods and results are shown below.

Thermal resistance

The thermal resistance test performed following EN ISO 15831, measure fabric

resistance to heat transfer. this property is essential for understanding the fabrics insulation capabilities in extreme temperature condition. The thigh and calf portion are very important sections for the comfort measurement and the area of measurements are shown in figure 3

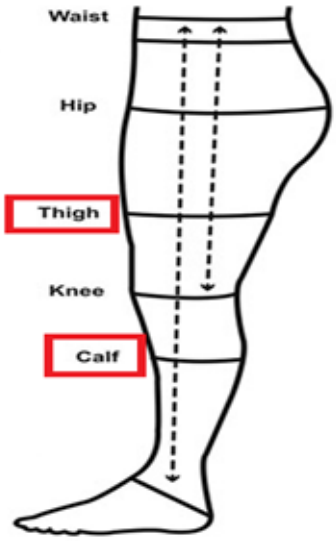

Figure 3. Calf and thigh area (Siddique HF, Mazari AA, Cirkl D, et al. 2023)

The results of the pants are shown in table 4

Table 4. Thermal resistance of the pants sections

Pants	Fabric information	Material	Color	GSM [g/m^2]	Thigh Rct [m.K/W]	Calf Rct [m.K/W]
1	Original	Polyester	Grey	330	0.25	0.18
2	Proban	Cotton	Blue	325	0.23	0.176
3	Denim	Cotton	Dark Blue	300	0.24	0.178
4	Workwear	Cotton/PES	Green	340	0.258	0.18
5	Fire man	Cotton/PES	Red	335	0.27	0.19

The thermal resistance of the chest or back part of the samples of shirts is shown in table 5.

Table 5. Shirts thermal resistance

	Shirt types	Front/back Rct [m.K/W]
1	Original	0.08
2	Original+ Cotton back	1.02
3	White jersey	0.0074
4	Quick dry strong	0.0072
5	White functional	1.014
6	Pink jersey	0.09
	Fabric of under arm	
7	Blue/white	0.02
8	Pink/white	0.024
9	Navy Blue/white	0.022

Water vapor resistance

The water vapor resistance test, conducted according to EN ISO 153831, evaluates the fabrics ability to resist the passage of water vapor. This property is crucial in determining the fabrics breathability and its ability to manage moisture. The results of the pants are shown in table 7

Table 6. Water vapor of the pants sections

Pants	Fabric information	Material	Color	Thigh Ret [Pa.m^2/W]	S.D [±]	Calf Ret [Pa.m^2/W]	S.D [±]
1	Original	Polyester	Grey	88	2.2	51.1	2.7
2	Proban	Cotton	Blue	101	4.1	64	3.2
3	Denim	Cotton	Dark Blue	76	1.7	43	1.2
4	Workwear	Cotton/PES	Green	85	4.7	46	2.2
5	Fire man	Cotton/PES	Red	98	5.9	74	3.4

The results are very important as the water vapor permeability is the main factor that defines the comfort of any workwear garment. The higher number shows that the less moisture can leave the fabric layers. It is obvious form the results that denim

showed excellent comfort properties in terms of the moisture permeability. The water vapor resistance of the chest part of the samples of shirts is shown in table 8.

Table 7. Shirts water vapor resistance

Shirt	Fabric information	CHEST Ret [Pa.m^2/W]
1	Original	3.9
2	Original+ Cotton back	5.7
3	White jersey	0.6
4	Quick dry strong	3.35
5	White functional	4
6	Pink jersey	4.35
	Fabric of under arm	
7	Blue/white	4.45
8	Pink/white	4.3
9	Navy Blue/white	5.5

The shirts include 2 kinds of material, one for the main body of the worker and second strips for the parts where high concentration of moisture exists like arms pits. According to the results the white jersey and the quick strong shows excellent results with minimum water vapor resistance. That means the sweat created be transported to the environment in very short times.

Tensile strength

The tensile strength of technical garments is very important and in this work, tensile strength is measured by using standard ISO 13934

Assessment of the fabrics resistance to breaking under tension. This test is performed at a speed of 100mm/min and a sample length of 200mm. Breaking strength value for both warp and weft directions are recorded.

Table 8. Pants fabric tensile strength

Pant	Fabric information	Material	Breaking strength WARP [N]	Breaking strength WEFT [N]
1	Original	Polyester	730	625
2	Proban	Cotton	1371	470
3	Denim	Cotton	1300	264
4	Workwear	Cotton/PES	990	705
5	Fire man	Cotton/PES	1450	1305

The result shows that the strength of the worker's garments in general have a very good mechanical strength but the fire fighter had the highest strength followed by the original pant and the proban fabric (also used as firefighter garment)

Table 9. Shirts tensile strength

Shirt	Fabric information	Breaking strength (course)	Breaking strength (wales)
1	Original	730	625
2	Original+ Cotton back	880	730
3	White jersey	180	129
4	Quick dry strong	680	353
5	White functional	520	313
6	Pink jersey	290	180
	Fabric of under arm		
7	Blue/white	184	150
8	Pink/white	345	193
9	Navy Blue/white	320	156

Knitted fabrics in general are not very strong in terms of mechanical strength and their main focus is generally comfort and functionality. The original garment and the quick dry showed highest mechanical properties.

Air permeability

Air permeability is very important factor in terms of comfort of any garments, the free air movement makes the microclimate dry and keep the person in comfort conditions. The results of shirts and the pants are shows below

Table 10. Pants air permeability

Pants	Fabric information	Material	Colour	GSM [g/m^2]	thickness [mm]	Thigh Rct [m.K/W]	Calf Rct [m.K/W]	Thigh Ret [Pa.m^2/W]	Calf Ret [Pa.m^2/W]	Air permeability [l/min]
1	Original	Polyester	Grey	330	1.2	0.25	0.18	88	51.1	73
2	Proban	Cotton	Blue	325	1.35	0.23	0.176	101	64	23
3	Denim	Cotton	Dark Blue	300	0.98	0.24	0.178	76	43	350
4	Work-wear	Cotton/ PES	Green	340	1.44	0.258	0.18	85	46	72
5	Fire man	Cotton/ PES	Red	335	1.59	0.27	0.19	98	74	29

The results show that the denim fabric has the highest air permeability, 3 times more than any other material in the category. Similarly, the shirts results can eb seen in the Table below

Table 11. Air permeability of shirts

Shirt	Fabric information	CHEST Rct [m.K/W]	Air permeability [l/min]	CHEST Ret [Pa.m^2/W]
1	Original	0.08	610	3.9
2	Original+ Cotton back	1.02	310	5.7
3	White jersey	0.0074	920	0.6
4	Quick dry strong	0.0072	630	3.35
5	White functional	1.014	570	4
6	Pink jersey	0.09	512	4.35
	Fabric of under arm			
7	Blue/white	0.02	470	4.45

Shirt	Fabric information	CHEST Rct [m.K/W]	Air permeability [l/min]	CHEST Ret [Pa.m^2/W]
8	Pink/white	0.024	530	4.3
9	Navy Blue/white	0.022	420	5.5

Higher the air permeability, better it is for the comfort of the textiles. The white jersey and the quick dry appeared to be the most breathable fabric.

Moisture management test

In the evaluation of fabric performance, the AATCC 195 standard introduces the concept of moisture managements specifically measured through the overall moisture management capacity (OMMC). This index serves as a crucial indicator, reflecting the fabrics ability to efficiently handle the transportation of liquid moisture.

Moisture management capability:

- Very good: The fabric demonstrates a highly effective ability to manage liquid moisture, with as OMMC in the range of 0.6-0.8.
- Good: The fabric has a commendable liquid moisture management capacity, ensuring efficient transfer of sweat from next to the skin to the outer surface.
- Excellent: The fabric excels in liquid moisture managements with as OMMC value higher than 0.8, indicating superior overall capability.

The additional detail in the table emphasizes the moisture management capability of each fabric, providing a comprehensive understanding of their performance in handling liquid moisture in extreme conditions. In essence, the OMMC becomes a valuable metric in assessing and categorizing fabrics based on their ability to handle liquid moisture, providing manufacturers and consumers with a standardized measure of performance.

Table 12. water management test results for pants

Pant	Fabric information	Material	Wetting time [s]	OMMC
1	Original	Polyester	9.54	0.78
2	Proban	Cotton	17.31	0.42
3	Denim	Cotton	13.17	0.53
4	Workwear	Cotton /PES	9.59	0.83
5	Fire man	Cotton /PES	12.1	0.92

Table 13: Moisture management of pant samples

Shirt	Fabric information	Wetting time [s]	OMMC
1	Original	88	0.8
2	Original+ Cotton back	52	0.71
3	White jersey	120	0.61
4	Quick dry strong	8.6	0.04
5	White functional	3.28	0.51
6	Pink jersey	3.43	0.50
	Fabric of under arm		
7	Blue/white	104.6	0.55
8	Pink/white	82.4	0.61
9	Navy Blue/white	114.1	0.54

A complete investigation of workwear samples designed for extreme heat temperatures was performed in this study. The samples, which included pants and shirts, were put through a series of tests to determine their physical, mechanical, and functional features.

Conclusions

A thorough examination of fabric characteristics and performance attributes in both pants and shirt samples yielded valuable insights for those looking for optimal workwear solutions.

The pant samples revealed characteristics customized for specific requirements. Proban Blue (Sample 2) demonstrated promising flame-retardant properties while remaining relaxed, making it ideal for hazardous environments. The green Cotton/Polyester blend (Sample 4) emerged as a versatile alternative, providing a commendable balance of mechanical performance and comfort—critical for workwear exposed to harsh conditions. The firefighter pant (Sample 5) performed admirably in terms of moisture management, ensuring quick liquid sweat transfer and skin dryness, which is especially important in extreme heat situations.

The best option for comprehensive workwear solutions is determined by the specific requirements. Sample 8 (Pink/White) and Sample 4 (Green Cotton/Polyester Blend) stand out as versatile options, providing a harmonious blend of performance and comfort. Individuals and industries should carefully consider their specific needs and environmental conditions. When considering the pants, the denim when choosing workwear to ensure the highest level of safety, comfort, and durability.

This analysis and recommendation offer valuable insights for workwear decision-makers, assisting them in making informed choices that are in line with the demands of their respective industries and working conditions.

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