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The Importance of Base Layer in Firefighting Operations

The aim of this study is to examine how base layers worn by firefighters contribute to comfort, thermoregulation, and freedom of movement during interventions, and how appropriate material composition can support the effectiveness of protective clothing. The research involved testing a base layer set in real interventions and practical scenarios with the participation of firefighters. Usage was documented by the author using a standardised evaluation form assessing the key aspects of comfort, thermal performance, freedom of movement, and functionality. The results indicate that the garments performed favourably in terms of thermal sensation and movement comfort; however, durability and overall satisfaction point to further opportunities for improvement. The study highlights that testing base layers is a process in which practical experience plays a key role and which may, in the future, contribute to improving the ergonomic and safety performance of protective clothing. The author also briefly presents a technological innovation, emphasising that subjective user experience-based evaluation should, in the future, be complemented with objective measurement data.

Keywords: firefighter, protective clothing, base layer, evaluation form, ergonomics

Introduction

Firefighting is one of the most demanding professions in terms of both physical and psychological strain, where wearing the required protective equipment is vital. During fire incidents and technical rescue operations, firefighters work in a complex, dynamically changing environment where maintaining safe working conditions is a constant challenge. Significant risks during interventions include high temperatures, smoke, toxic gases, and accident factors arising from structural instability. Due to climate change, industrial and technological development, the nature of hazards has changed over recent decades. Increasingly frequent extreme weather events require new types of interventions, further increasing physical

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workload. In addition, the spread of hybrid and fully electric vehicles poses specific risks, as battery-related fires can be difficult to control.²

During interventions, firefighters are exposed to numerous carcinogenic substances and combustion by-products, which may increase the risk of developing cancer in the long term. According to the most recent research findings, the incidence of bladder and prostate cancer, in particular, shows an elevated trend.³ Their profession also involves substantial psychological strain: traumatic events, heightened responsibility, and continuous readiness increase the risk of post-traumatic stress, depression, and anxiety. Over the long term, mental strain may adversely affect not only psychological well-being but also physical performance and the safety of decision-making.⁴

The complex layering system of protective clothing designed for firefighters aims to balance thermal protection, mechanical resistance, and freedom of movement. One key – yet often underestimated – component is the base layer, which comes into direct contact with the wearer's skin and primarily serves to wick moisture and ensure thermal comfort. Numerous studies have shown that overheating and heat stress not only reduce comfort but also adversely affect reaction time and decision-making ability.⁵ Overheating may be accompanied by, among other symptoms, heavy sweating, an increased heart rate, intense thirst, nausea, headache, or dizziness. At high ambient temperatures, the body's protective mechanisms (elevated heart rate, increased breathing, etc.) are rapidly exhausted, leading to rapid dehydration, reduced concentration, and decreased performance. When heat dissipation is no longer possible, core body temperature rises to a dangerous level and heat stroke may develop, potentially resulting in a stroke.⁶

Urbán and Restás point out that firefighters are exposed to significant heat stress during interventions, which places a burden on their body's thermoregulation and circulatory system. Full-body protective clothing, high external temperatures and heavy physical work together rapidly increase body temperature, resulting in reduced performance and concentration. The authors emphasise that overheating may lead to exhaustion, heat stroke, fainting and in extreme cases death. Based on a review of the literature, the study presents various options and tools that may help reduce body temperature, especially during interventions. The main conclusion of the article is that the application of appropriate cooling solutions can contribute to more effective and safer work for firefighters. In my opinion, the study has provided and continues to provide an excellent basis for identifying development directions in this field, however, the presented solutions add extra weight for firefighters, which would mean additional physical strain, therefore I would only support proposal focusing on cooling.⁷

Pántya and Horváth highlight that the multi-layered design of firefighter's protective clothing is important not only for ensuring an adequate level of protection, but also for

² PÁNTYA–HORVÁTH 2023a.

³ ERNST et al. 2025.

⁴ OLIVEIRA et al. 2023.

⁵ HORVÁTH 2023.

⁶ DWORNIK–BINKOWSKA 2023.

⁷ URBÁN–RESTÁS 2017.

meeting ergonomic and comfort requirements. In warm environments, one of the essential functions of the clothing is to absorb sweat and transport moisture away, thereby reducing the risk of heat exhaustion and heat stress. The thickness and material composition of the layers are determining factors in terms of thermal insulation and vapour permeability. The article emphasises that the material of the base-layer has the greatest effect on overall comfort, as it is in direct contact with the skin and play a primary role in sweat management.⁸

Matusiak and Sukhbat demonstrated through experimental methods that hygroscopic and capillary processes occurring between the base layer and the layers of protective clothing decisively influence sweat transport and the development of the skin-surface microclimate. Their investigations also showed that, in certain textile assemblies, sweat can accumulate, increasing the likelihood of heat stress. The authors emphasise that optimising the material, fabric structure, and fit of the base layer can significantly improve the wearability of protective clothing and, consequently, the user's performance.⁹

Stygiené et al. investigated double-layer knitted textiles in which the inner layer contained aramid yarn, while the outer layer consisted of an aramid-flame-retardant viscose blend. Their objective was to assess the suitability of these materials as base layers under extreme thermal exposure. The authors emphasised that such materials must provide not only flame resistance but also regulation of the microclimate in the immediate vicinity of the skin, which fundamentally determines perceived comfort during wear. During the study, knitted structures with different patterns and surface designs were tested, and flame resistance, liquid moisture management, water vapour and air permeability, as well as thermal resistance were analysed. Their results showed that all examined textiles met breathability requirements. The best overall performance was observed for materials whose skin-contact surface was porous and embossed. The research highlighted that heat and moisture regulation properties were influenced more strongly by the material structure and surface topology than by the fibre composition itself. In contrast, flame-resistance behaviour primarily resulted from the aramid and flame-retardant viscose yarns used and did not show substantial differences across the various structures. The study concluded that, in the development of base layers, it is not sufficient to merely apply appropriate flame-resistant materials; particular attention must also be paid to the structure and patterning, which can significantly improve thermal comfort.¹⁰

Zupin et al. explored the comfort and flame-resistance properties of knitted fabrics made from different materials and structures that can be used as base-layer garments for operational firefighters. They examined four different materials (cotton, Tencel, Micromodal) and one flame-resistant blend (Tencel, polyacrylate, Modacryl-Tayrilan). Their measurements showed that the knitting structure has a greater effect on fabric density and dimensional stability than fibre composition. The blend proved more stable after washing than cotton. Air permeability was influenced primarily by the material type: Tencel was the most breathable, while cotton was the least. In terms of thermal conductivity, cotton conducted heat most

⁸ PÁNTYA-HORVÁTH 2023b.

⁹ MATUSIAK-SUKHBAT 2024.

¹⁰ STYGIENÉ et al. 2022.

effectively, whereas the flame-resistant blend provided greater insulation. Micromodal showed the best water vapour permeability, while the blend wetted through the slowest. Flame-resistance testing indicated that only the blend was truly flame resistant. Based on the results, this blend is suitable for manufacturing and use as a firefighter base layer, as it combines safety and comfort characteristics. The authors recommend further research to examine applicability within combinations of multi-layer protective clothing systems. In my view, the article addresses an issue that is already a relevant problem today, and it is indeed worth pursuing further research in this area.¹¹

Eryuruk et al. examined firefighters' protective clothing and its heat and moisture transport properties, with a particular focus on a newly developed flame-resistant base layer. The starting point of their research was the recognition that balancing firefighters' comfort and safety remains challenging, as adequate thermal protection typically comes with less effective ventilation. In their investigation, they applied an innovative base layer made from a blend of para-aramid, flame-resistant viscose, and antistatic materials, and analysed its effects across different clothing-layer combinations. Standardised test methods were used, including FTIR¹² and SEM-EDX¹³ analyses to characterise material structure. The new base layer had a favourable effect on one-way moisture transport, meaning that sweat was more effectively transferred from the skin-adjacent layers toward the outer layers. Based on thermal resistance measurements, multi-layer combinations provided greater protection but lower air permeability, clearly demonstrating the trade-off between comfort and protection. Overall, the results suggest that using the new base layer may improve firefighters' comfort during work and thereby indirectly enhance operational effectiveness, while not significantly compromising protective performance.¹⁴ One strength of the study is that the authors combined physical material testing with comfort assessments and adopted a systems-level approach, enabling a detailed mapping of interactions between clothing layers. A limitation of the research is that the measurements were conducted under laboratory conditions; therefore, real firefighting environments were not modelled. Consequently, the study's findings primarily provide a theoretical and developmental basis.

According to the conclusions of the study by Šajatović et al., the protective clothing system examined can provide adequate protection under flame exposure only if it is fully intact and used together with a firefighter base layer. The authors emphasised that the base layer plays a decisive role in preventing injuries and that, in its absence, the user would suffer significantly more burn injuries. They considered simple cotton base layers to be particularly hazardous, as cotton absorbs moisture more quickly and the resulting steam would cause burn injuries to affect a larger area. The authors also pointed out that during prolonged interventions (e.g. wildland or vegetation fires), damaged clothing or improperly layered systems would not provide sufficient thermal protection. In the development of protective clothing, not only the selection of materials but also the functional interaction between layers is important. The

¹¹ ZUPIN–KNIFIC–ČUDEN 2022.

¹² FTIR: Fourier-transform infrared spectroscopy.

¹³ SEM-EDX: Scanning electron microscopy and energy-dispersive X-ray spectroscopy.

¹⁴ ERYURUK et al. 2022.

article highlights the need for closer cooperation among developers, manufacturers, materials engineers, and end users to ensure that the clothing truly meets practical demands.¹⁵ In my assessment, the authors' emphasis on the necessity of such collaboration is fully justified, and I agree that only this type of joint effort can lead to modern protective clothing that performs adequately in real-world practice.

The literature review clearly indicates that an appropriate base layer – together with its material composition and design – plays a fundamental role in reducing heat strain and preventing injuries. Building on this insight, the next chapter presents a base-layer trial/test conducted by the author, which evaluates the performance of different solutions under real-world conditions. The results of the test are then analysed in detail.

Functional base layer testing and user feedback

In the following, I present the results of a trial of a base-layer set consisting of a leggings (Figure 1) and long-sleeved top (Figure 2). Based on the author's request, the manufacturer modified the base layers, therefore their design and material composition differ from the specifications listed on the manufacturer's website.



Figure 1: Leggings

Source: compiled by the author



Figure 2: Long-sleeved top

Source: compiled by the author

¹⁵ ŠAJATOVIĆ – FLINČEC GRGAC – ZAVEC 2022.

The material composition of both the top and the leggings is as follows:

- 57% modified acrylic
- 37% cotton
- 5% elastic fiber
- 1% antistatic fiber¹⁶

The design of both garments is intended to support ease of movement, stable thermoregulation, and compliance with safety requirements. A total of four Polish firefighters participated in the test and evaluated the comfort and usability of the garments based on short-term wearing experience during organised practical training sessions and real firefighting incidents. The questionnaire used was developed by the author; therefore, its structure and focus areas were aligned with the objectives of the research. Although, due to the small sample size and limited duration of the trial (approximately three weeks in July 2025), the results are only representative to a limited extent, they nevertheless provide an important starting point for further development. The trends emerging from the feedback clearly indicate how modifications may influence comfort and functional performance in practical use.

The Likert-scale questionnaire related to the base layers examined five main domains: perceived comfort, thermoregulation, freedom of movement, functionality and durability, and overall satisfaction. The use of a five-point scale made it possible for the trial participants' subjective experiences to be captured in a consistent structure and to become quantitatively comparable. The "Comfort" section assessed how well the garment fit the body, whether it caused any irritation, and how well it supported comfort during everyday use. The "Thermal sensation and thermoregulation" section evaluated the breathability, sweat management, and perceived comfort of the material across different temperature conditions. The "Freedom of movement" domain examined to what extent the garment hindered or supported movement during work and how compatible it was with protective clothing, particularly when donning the turnout gear. The "Functionality and durability" items focused on shape and material retention, cleanability, and the garment's contribution to the overall performance of the protective clothing system. Finally, the "Overall satisfaction" section assessed users' overall impression and their willingness to recommend the product. The selection of these domains was justified because they most strongly determine the practical usability of base layers in a firefighting environment. The questionnaire responses provided by the firefighters were averaged by the author within each domain, resulting in a single, standardised score for each category.

Based on Table 1, for the leggings, the highest score was obtained for "Functionality and durability" (4.58), indicating that the trial participants were satisfied with the material quality, shape retention, and the extent to which the garment contributed to the wearing comfort of the protective clothing system. "Comfort" received an average score of 4.33, suggesting that the leggings fit well and provided adequate comfort. The "Freedom of movement" score

¹⁶ See: <https://pwkrystian.com>

of 4.25 is also favourable, as the garment did not meaningfully hinder performance during work. The "Thermal sensation and thermoregulation" score of 4.00 suggests that the leggings managed moisture and breathability appropriately, although there may be opportunities for fine-tuning in this area. The "Overall satisfaction" score of 4.00 reflects positive feedback overall: participants were generally satisfied with the base layer, and based on their overall impression, it provides a suitable starting point for further development.

Table 1: Summary of user feedback from the trial use of the base layer leggings

Aspects	Rating
Functionality and durability	4,58
Comfort	4,33
Freedom of movement	4,25
Thermal sensation and thermoregulation	4
Overall satisfaction	4

Source: compiled by the author

Table 2 presents the user evaluation of the base layer top, which showed moderate results. During the trial, the highest scores were given to "Freedom of movement" and "Thermal sensation and thermoregulation," both with a value of 4.25, indicating that the top adapted well to workloads of different intensity, did not restrict movement, and managed heat dissipation appropriately during the exercises. The result for "Comfort" (4.17) suggests that the trial participants had relatively positive experiences regarding wearability, although the score is slightly lower than the value observed for the leggings. This may indicate that certain details (e.g. seam placement) could require minor fine-tuning; nevertheless, comfort remains one of the strengths of the top. From the perspective of "Functionality and durability," the top achieved a score of 3.92, which is stable but somewhat more restrained. The lowest score was recorded for "Overall satisfaction" (3.75), indicating that the participants considered the top less outstanding than the leggings. Based on the feedback, the top may serve as a suitable starting point; however, the necessary fine-tuning could further increase overall user satisfaction.

Table 2: Summary of user feedback from the trial use of the base layer top

Aspects	Rating
Freedom of movement	4,25
Thermal sensation and thermoregulation	4,25
Comfort	4,17
Functionality and durability	3,92
Overall satisfaction	3,75

Source: compiled by the author

The results of the trial use align well with the principle that the development of protective clothing requires continuous testing and multiple iterations. As the tests were not conducted under laboratory conditions but in real training or intervention scenarios, the evaluation inherently reflects the subjectivity of user experience and the variability of everyday workload conditions. Due to the short duration and the limited number of participants, the findings cannot be considered comprehensive; however, they provide important guidance on which modifications improved comfort and functionality and where further development is justified. In this form, user feedback represents added value because it demonstrates garment performance in a realistic field environment, thereby contributing to the development of a base-layer set that is reliable in the long term and proven in practice.

In addition to subjective evaluation, instrument-based data collection can also provide useful information, as it can help confirm personal responses related to wearing the garments. In the following, the author presents a technology that, given the current state of the art, can be considered novel and is highly suitable for the objective interpretation and evaluation of the collected data.

Instrument-based support

Equival's solution recommended for firefighter (first responder) applications can logically be described as the pairing of a wearable sensor and a central server/software platform. During interventions or training, continuous and objective data are available on firefighters' physiological workload, which can support the early identification of overload and heat-stress risk. One component of the system is the eq02+ LifeMonitor, which is worn as a chest strap/belt and is designed to measure multiple physiological parameters simultaneously. According to the manufacturer's specifications, the device is designed for environmental conditions that may be encountered during field use (e.g. temperature range, water resistance). The other wearable device is the eq LifeBand, which is provided in an armband format. Based on the available descriptions, the device connects to the Black Ghost system and enables the use of individualised thresholds and alerts; the manufacturer also emphasises alignment with professional heat-stress guidelines. The hardware components are integrated by the Black Ghost software, which provides centralised data visualisation and analysis, thereby offering command staff a clear, real-time overview of personnel workload.¹⁷

The Core Temperature Monitoring function within the system appears to be a particularly interesting innovation: it provides true core temperature data in addition to conventional physiological signals (e.g. respiratory rate, heart rate) by using an ingestible (non-digestible) capsule. According to the product page, this solution is implemented in conjunction with BodyCAP eCelsius capsules and the Equival sensor system. The capsule weighs only 1.7 g and reports values with an accuracy of ± 0.2 °C, enabling simultaneous monitoring of up to eight individuals. The description also provides information on battery life: 20 days when using

¹⁷ See: <https://equivital.com/industry/first-response>

a 30-second measurement interval.¹⁸ I consider the option for group monitoring particularly advantageous, because the measured and evaluated data make it possible to compare the physiological workload associated with different assignments and on-scene roles, which could later provide a basis for fine-tuning organisational practices.

I consider this solution particularly strong as a first step for piloting and proof of concept, primarily in a training environment and during interventions where heat strain is typically elevated (e.g. enclosed-space operations or work performed in summer heat). In addition, it could also be applied in the evaluation of the base layer experiment described, so that the assessment would not rely solely on firefighters' subjective feedback but could be supported by objective physiological data as well. When interpreted side by side, the measurement results and the numerical outputs of the wear-trial evaluation form can reinforce the conclusions; in cases of contradiction, they can also provide an early indication that a given factor (e.g. material, design) requires further review, allowing the necessary corrections to be implemented more quickly.

Summary

Based on the results of the research, I have concluded that further development of base layer garments remains justified. The practical trials showed that the modified garments performed well in several respects, but did not produce equally strong results across all domains. Freedom of movement and comfort received particularly positive feedback; however, several remarks were made regarding overall satisfaction. These findings imply that the current solutions remain provisional. Due to the short testing period and the small number of participants, the conclusions are limited, but they clearly indicate the main directions for improvement.

The diversity of real intervention scenarios provided valuable feedback on how the materials perform in practice. Practical experience also brought to light several factors that cannot be assessed precisely under laboratory conditions. Workloads of different intensity revealed different potential failure points or comfort-related differences. Participants' observations highlighted that the behaviour of base layers is highly dependent on the type of intervention. Overall, the trial experience demonstrates that base layer development is not a one-off task; longer wear periods and a larger sample are required for a more robust assessment.

Based on the foregoing, it is evident that the experience gained from the wear trial is valuable; however, the reliability of the conclusions would be enhanced by complementing subjective feedback with objective physiological measurements. I also reviewed this possibility through a market example: Equivital's Core Temperature Monitoring solution applies ingestible capsule-based core temperature monitoring, which can quantitatively track workload and heat-stress trends in line with real operational conditions. As a result, research on base layer testing could rely not only on perceived sensations but also on measurable parameters confirming user experience when the findings align, and providing timely indication of the need for further fine-tuning when discrepancies occur.

¹⁸ See: <https://equivital.com/products/bodycap-core-temperature-pills>

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