ABSTRACTS

8th EUROPEAN CONFERENCE on PROTECTIVE CLOTHING
Upcoming Generation

Hosted by citeve
TEXTILE TECHNOLOGY

Organized by
8th EUROPEAN CONFERENCE on PROTECTIVE CLOTHING
Upcoming Generation

7th to 9th of May 2018
Porto, Portugal

Organized by:
citeve
TEXTILE TECHNOLOGY

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The 8th European Conference on Protective Clothing is organized by CITEVE – Technological Centre for the Textile and Clothing Industries of Portugal in association with the European Society of Protective Clothing (ESPC), the Federation of the European Union Fire Officer Associations (FEU), the Institute for Safety (IFV) and the European Safety Federation (ESF).

The conference intends to be a platform to disseminate, to exchange and to discuss the results of research, project developments and implementation programmes related to protective clothing, with a strong focus on user protection and well-being, installing a dialogue between industries and academic organizations. In addition, the purpose of the “Firefighters Theme Day” is to initiate interaction between end-users and scientists to create a better understanding of their worlds. Industrial partners can benefit from this to develop more task-specific products based on the functional needs of the end-users.

A 3-day conference, in the unique setting of Porto historic city, will bring together industry innovators, technology providers, researchers, clusters and other actors from the Protective Clothing industry sector from across Europe.

An event full of opportunities to explore, learn, share and of course do networking, through an attractive well-balanced programme of presentations, posters and discussion sessions is awaiting you! The conference will embrace domains like integrated electronics/smart textiles, product safety, ergonomics, comfort, sustainability, regulatory aspects and, in addition to the regular ECPC/NOKOBETEF, a supplementary and important theme day dedicated to the needs of Firefighters will contribute to the conference success.

This conference is intended for researchers, designers, manufacturers, purchasers, experts in health and safety and human factors, public authorities (procurement), and end-users.

We would like to thank to all sponsor companies, to all authors and participants for their kind supports. We hope that this international event will also generate an occasion to create new opportunities.

We are happy to welcome you.

About CITEVE

CITEVE is a Technological Institute which provides technological support and services to companies acting in the textile & clothing business. The Institute facilities are settled in Portugal (Vila Nova de Famalicão) with complementary fields of expertise, and also six international branches, namely in Brazil, Tunisia, Argentina, Pakistan, Chile and India.

Product design & development, prototyping, testing and applied R&D oriented to innovative applications, are included in a service portfolio that also includes consultancy, training and fashion intelligence.

Being diligent for three decades, CITEVE is an active member of several international networks and also takes part in different technical working groups in the fields of research, product testing and certification. As a private non-profit organization, the Centre ensures an effective link to the public sector, both at national and European level, namely with an important contribution in the definition and implementation of public policies, relevant for the textile & clothing industry.
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Liaison partners

Roger Barker

Emiel den Hartog

Kee Jong Yoon

Asian Society of Protective Clothing
AsianPacific

Eun Ae Kim

Kaoru Wakatsuki

Organizing Committee
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*the entities were listed in alphabetical order*
8th EUROPEAN CONFERENCE on PROTECTIVE CLOTHING
Upcoming Generation

MONDAY, 7TH OF MAY

10H30  Registration

ROOM A

11H15  Opening Session
//11H30  Biaz Costa, CITEVE (PT) - Welcome Address

11H30  Plenary Session: Megatrends
//12H30  Robots don’t wear PPE
Jan Lapere, Cenlexel (BE)
Linking University Research Centers to Society - A Portuguese Experience
Divo Quintela, Coimbra University (PT)

12H30  LUNCH

14H00  SESSION 1: Protection Against Contaminants
//15H30  Effect of Smoke and Particulate Blocking Layers on Performance of Firefighter Protective Hoods
Roger Barker, North Carolina State University (US)
Game-Changing Technology for Next Gen Firefighters PPE
Allens Heli, DuPont Safety & Construction (US)
Technical Requirement Analysis of Personal Protective Equipment Under Complex Disaster Environments
Ming Fu, Tsinghua University (CN)
Performance Evaluation of the Personal Protective Clothing Indoor Chemical Exposure Modeling and Transdermal Uptake Calculation
Na Luo, Tsinghua University (CN)

15’ Discussion

15H30  COFFEE BREAK

16H00  SESSION 2: New Methods and Standards
//17H45  Chair: Peter Heffets, BS BAU (DE)
Analyzing the Effects of Washing Processes and Wear on Fabric Friction Sound of Soldiers Uniforms
Fioriane Leclince, Laboratoire de Physique et Mécanique Textile (FR)
Air Gap Measurement in Firefighter Clothing by a 3-D Body Scanner and its Application to Heat Transfer Analysis
Kazru Wakatsuki, Shinshu University (JP)
Protective Clothing Against Cold - Impacts of the Standard Revision
Kater Muijlane, Lund University (SE)
An Automated Control System for Testing Resistance of Protective Clothing Materials to Penetration by Liquids under Pressure
Eva Cohen, Instituto Nacional de Seguridad, Salud y Bienestar en el Trabajo (ES)
Study on the Evaluation Method of Protective Effect of Individual Protective Equipment Based on Human Model
Jianan Tang, First Research Institute of the Ministry of Public Security of PRC (CN)

15’ Discussion

16H00  SESSION 4: New Materials, Functionalizations and Technologies
//17H45  Chair: Guido Santos, CITEVE (PT)
Evaluation of “The End Of Service Life” of Self-Healing Materials Applied in All-Rubber Protective Gloves
Anna Bacciarelli-Ulacha, Central Institute for Labor Protection - National Research Institute (PL)
A Knitted Fabrics for Protection Against Mosquito Bites without the Use of Insecticides
Emre DenHartog, College of Textiles, North Carolina State University (US)
Effect of Knitting Pattern on the Electromagnetic Shielding Efficiency of the Knitted Fabrics Produced with Electro-Conductive Yarns
Ali Serkan Soydan, Pamukkale University (TR)
Preparation of High Temperature Resistant Fabrics with High Thermal Shock Resistance
Hao Feng, Donghua University (CN)
Investigation of Effects of Phase Changing Materials Transfer By Coating Method
Gültekin Kartal, Dokuz Eylul University (TR)
High-Impact Technology for Motorcycle Wear
Nelson Oliveira, Possible Answer (PT)

15’ Discussion

17H45//18H15  ORAL POSTER PRESENTATION

18H15//19H00  ESPGC GENERAL MEETING
TUESDAY, 8TH OF MAY

ROOM A

09H00 SESSION 5: Sports and Medical Protection
Chair: George Havenith, Loughborough University (UK)
- Development of Test Methods for Clothing Protecting Against Bites by Ticks (Ixodidae)
  Aden Porok, Central Institute for Labour Protection National Research Institute (PL)
- A New Test Method to Evaluate Fluid Leakage at the Glove and Protective Clothing Interface
  F. Selcen Kilinc-Balci, Centers for Disease Control and Prevention National Institute for Occupational Safety and Health (US)
- Surgical Gowns: Measurements of Clothing Insulation with a Thermal Manikin
  A. Virgilio M. Oliveira, ISCE/IPC (PT)
- A Method to Evaluate the Barrier Performance of Protective Fabrics using Visual 'Strikethrough' as a Surrogate Viral Penetration Test
  Lee Portnow, National Institute for Occupational Safety and Health - NIOSH (US)
- Development of a Motorcycle Ensemble: Clothing Insulation Approach and Measurements with a Thermal Manikin
  Gilda Santos, CITEVE (PT)

10H40 COFFEE BREAK

11H00 SESSION 6: Ergonomics and Comfort
Chair: Grażyna Bartkowiak, Central Institute for Labour Protection National Research Institute (PL)
- Shoe Climate Optimization in Working Boots
  Martin Harnisch, Hohenstein Institut fuer Textilverbraucherinnovation (DE)
- Evaluating the Ergonomics of PPE Systems - How Many Subjects are Needed?
  Peter Bröde, Leibniz Research Centre for Work Environment and Human Factors (IWW) (DE)
- The Influence of Passive Cooling during Recovery on the Validity of Predicting Firefighter's Core Body Temperature by Resting Heart Rate
  Suyeon Kim, Seoul National University (KR)
- Non-invasive Heat Strain Detection for Passive and Active Heat Exposure
  Simon Annandale, Emma (CH)
- A Weight Thresholds For Physiological and Subjective Strain According to Weight Increase in Fire-Protective Boots Between 3.2kg to 5.3kg
  Sanghyun Roh, Seoul National University (KR)
- New Protective Clothing to Reduce Heat Stress and Increase Comfort for Operators in the Metal Industry
  Marni Sandsand, SINTEF Technology and Society (NO)

12H40 LUNCH

14H00 SESSION 7: Selection, Safe Use, Maintenance and Lifecycle
Chair: Daniela Zavec, TITERA (SI)
- Workwear for Multi Protection of Personnel on Sea Objects of the Arctic Offshore
  Elena Lebedeva, Evgenievich (RU)
- Functionality of Workwear Clothing based on Dimensioning Silhouettes and Users Preferences
  B. Brita Møller, Textile Institute, Department of Knitting and Clothing Technologies (PL)
- Comparison of the Effect of Thermal Aging on the Mechanical Performance of Fire Protective Fabrics
  Patricia Dolez, University of Atterica (CA)
- Comparison of Physical and Barrier Performance of Reusable Isolation Gowns
  F. Selcen Kilinc-Balci, Centers for Disease Control and Prevention (US)
- Incident Heat and Temperature and Humidity in Firefighter's Gear During Firefighting With Wireless Sensing
  Ruytaro Seto, Shintetu University (JP)
- PPE manufacturing 4.0 - supporting manufacturers in implementing the new EU PPE regulation
  Arash Rezeay, Institut für Textiltechnik der RWTH Aachen University (DE)

15H00 PANEL DISCUSSION (25 Discussion)
Chair: Ricardo Weeber, Professor, Institute for Safety - NL
- Pedro Rios, Federation of the European Union Fire Officer Associations (PT)
- Roger Barker, Scientist North Carolina State University (US)
- Juha Laitinen, Finnish Institute of Occupational Health (FI)
- Stephanie Conings, Fire Service Amsterdam (NL)
- Maurice Kemmeren, Institute for Safety (NL)

ROOM B

09H00 Opening Theme Day
- Changing Environments in Relation to Protective Clothing
  Maurice Kemmeren, Institute for Safety (NL)

09H30 SESSION 1: Wildland Firefighting
Chair: Ronald Heus, Institute for Safety (NL)
- Advanced Fire Shelters for Wildland Firefighters
  Roger Barker, NC State University (US)
- PPE Concerns Wildland Firefighting
  Vincent Dubois, SDIS 13 Sapeurs Pompiers Des Bouches Du Rhone (FR)
- Heat Transfer Characteristic by Water Content of Outer and Thermal Liner in Firefighter Clothing Against Ordinary and Routine Heat
  Kaeoru Watsuki, Shinshu University (JP)

10H Discussion
**TUESDAY, 8TH OF MAY**

**ROOM A**

16H00 //17H40 SESSION 8: Thermoregulatory Systems for Protective Clothing
Chair: Kaoru Wakatsuki, Shinshu University (JP)
Evaluation of Different Ambient and Clothing Conditions for Threshold Limit Value of Occupational Heat Stress: Pilot study
Jung-Hyun Kim, National Institute for Occupational Safety and Health (US)
Use of A Human Body Thermoregulation Model to Evaluate Fire Protection Clothing
A. Virgilio M. Oliveira, University of Coimbra (PT)
Comparison of Thermal Manikin Modeling and Human Subjects Responses During Use of Cooling Devices Under Personal Protective Ensembles in the Heat
Ajitar Coca, CCN/VOSH (US)
Effect of Moisture in Undergarments on Protective Parameters of Clothing Set Protecting Against Heat and Flame
Gratyna Berkowitz, Central Institute for Labour Protection - National Research Institute (PL)
Influence of Perspiration Simulated on Thermal Hand Model on the Insulation of Protective Gloves in Cold Thermal Environment
Anna Bacciarelli-Ulacha, Central Institute for Labour Protection - National Research Institute (PL)
User Centered Product Development of a Cooling Garment for Firefighters
Marijke Timmermans, Saxion University of Applied Sciences (NL)
10’ Discussion

17H40//18H10 ORAL POSTER PRESENTATION

CONFERECE DINNER AT CAVES REAL COMPANHIA VELHAA WITH GUIDED VISIT TO PORTO’S WINE CELLAR

(Transfer at 18:00 from Sheraton Lobby)

**WEDNESDAY, 9TH OF MAY**

**ROOM A**

09H00 //10H40 SESSION 9: New Methods and Standards
Chair: Eric van Wely, DuPont Safety & Construction (CH)
Testing Method of Test on Firefighter Gloves Against Heat and its Evaluation of Current Products
Kaoru Wakatsuki, Shinshu University (JP)
PPE for Protection Against Pesticides: Development Of Surrogate Test Chemical
Angurah Shaw, University of Maryland Eastern Shore (US)
Development of Chemical Protective Clothing Evaluation Device
Hao Feng, Donghua University (CN)
Use of Spectrophotometry UV-VIS In The PPE For Protection Against Pesticides Assessment
Hamid Humberto Ramos, Agronomic Institute (BR)
Characterization of the Surface Tension of Synthetic Blood Used In ISO 16603 Penetration Tests
Lee Ponnoff, National Institute for Occupational Safety and Health (NIOSH) (US)
Protection Against Hot Steel Injuries: How Does Steam Penetrate the Human Skin?
René M Rossi, Empa, Swiss Federal Laboratories for Materials Science and Technology (CH)
10’ Discussion

10H40 COFFEE BREAK

11H00 //12H40 SESSION 10: Smart Systems and Wearables for Protective Clothing
Chair: René Vanhoutte, European Safety Federation (BE)
A Software for Body Injury Assessment and Performance Evaluation of Personal Protective Clothing
Ming Fu, Tsinghua University (CN)
A Kind of Thermal Barrier with Intelligent Adjustment Thickness
Hongting Liu, Donghua University (CN)
Development of Sensorized Protective Personal Equipment for Hazardous Environment and Operative Personnel Assessment
André Pinto, CeNTI (PT)
Sensor-based Wearable Airbag Systems for Various Fall Scenarios
Jan Vincent Jordan, Institut für Textiltechnik (ITA) der RWTH Aachen University (DE)
WeSENSS: Wearable Wireless Devices for Vitals and Body Area Environment Monitoring of Firefighters
Jako Paulo Coimbra, INESC-TEC Porto (PT)
Smart PPE Standardization Issues
Gilda Santos, CITEVE (PT)
10’ Discussion

12H40 CLOSING SESSION AND AWARDS CEREMONY

13H30 SOCIAL PROGRAM - DOURO RIVER’S CRUISE WITH LUNCH (under payment and subjected to a minimum number of participants)
MONDAY, 7TH OF MAY

ROOM A

17H45/18H15 ORAL POSTER PRESENTATION Chair: Bengi Kutlu, Dokuz Eylül University (TR)

A Review on Thermal Protection
Ana Lelito, Fibrenamics - 2C2T - University of Minho (PT)

Can Professional Footwear Help Reduce Fatigue of Professionals in the Logistics Sector?
Ana Rita Pedrosa, Lavoro Europe (PT)

Comparison of Thermal Insulation of Protective Gloves with Passive and Active Heating Systems
Emilia ǖrzmańska, Central Institute for Labour Protection | National Research Institute (PL)

Design Potentials of Magnetic Yarns
Erin Lewis, Swedish School of Textiles, University of Borås (SE)

Development and Assessment of a Technical Material for Construction Workwears
Ran-i Eom, Chungnam National University (KR)

TUESDAY, 8TH OF MAY

ROOM A

17H45/18H15 ORAL POSTER PRESENTATION Chair: Hilde Faarvik, SINTEF Health Research (NO)

Development of PPE Garment Prototypes for Pesticide Operators
Sonja Sjarman, University of Maribor (SI)

Evaluation of Manual Dexterity of Protective Gloves with Heating Elements for Cold Environment
Paulina Krojańska, Central Institute for Labour Protection, National Research Institute (PL)

Variability on Tests Results Using ISO 17491-4 with Different Spraying Nozzles - PART II
Hamilton Humberto Ramos, Agronomic Institute (BR)

Additive Manufacturing Technology for Smart Textiles
Tanvir Ahmed, Centria University Applied Sciences (FI)

Chemical Protection and Detection for Composite Functional Fabrics
Hongling Liu, Donghua University (CN)

Smart Integration of Protective Clothing and Portable Cutting Devices for Forest Operations
Tetsuya Matsumura, Tokyo University (JP)

ROOM B

17H45/18H15 ORAL POSTER PRESENTATION Chair: Kaiju Kuklane, Lund University (SE)

Simulation of the Human Body Thermophysiological Response Using the HuTheReg Software
A. Virglio M. Oliveira, University of Coimbra (PT)

Interactive Systems for Emergency Teams
Clementina Freitas, Latino Group (PT)

An Integrated Numerical Simulator for the Prediction of Firefighter’s Heat Strain and Burn Injury
Jiansong Wu, China University of Mining and Technology (CN)

Smart Work Wear - Smart Helmet
Jari Isohanni, Centria University of Applied Sciences (FI)

The Specialized Clothing for the Firefighters - Estimation the Air Temperature for Feeling the Thermal Comfort
Magdalena Małyńczuk, Central Institute for Labour Protection, National Research Institute (PL)
TARGET GROUPS
This conference is intended for researchers, designers, manufacturers, purchasers, experts in health and safety and human factors, public authorities (procurement), end-users and other actors from the Protective Clothing industry sector from across Europe.
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07, 08, 09 May 2018

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EFFECT OF SMOKE AND PARTICULATE BLOCKING LAYERS ON PERFORMANCE OF FIREFIGHTER PROTECTIVE HOODS

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Introduction
Firefighting has long been believed to be one of the more hazardous occupations, mainly due to the potential exposures to extreme heat and the physiological thermal stresses that firefighters experience daily. However, as burn injuries to firefighters continue to decrease (1) due to more protective turnout ensembles and more cautious fire suppression tactics, it is now being realized that a major hazard firefighters face is the exposure to toxic combustion products in smoke and soot which contain numerous suspected carcinogens. Although most of the turnout ensemble envelopes the firefighter’s body in overlapping layers of outer shell materials, moisture barriers, and thermal liners that provide adequate protection from the thermal hazards as well as limited protection from infiltration of particulates and aerosols, for many firefighters, large areas of the head and neck are only protected by a thin, double layer knit protective hood. While a knit hood constructed of flame resistant materials should sufficiently provide the required level of thermal protection, the open knit structure allows for smoke and soot particles containing carcinogens to easily penetrate through the hood and deposit on the skin of the firefighter’s head and neck. Deposition of soot following fire suppression activities has been anecdotally described by numerous firefighters (2) and can be clearly seen in the results of a fluorescent aerosol protection test as shown by the green/blue fluorescent areas in Figure 1.

Traditionally, the main requirements for protective hoods certified for use by firefighters in the United States and specified by the National Fire Protection Association (NFPA) have only included thermal protective performance and mechanical properties (3). However, in the past few years, protective hoods with new particulate blocking layers or moisture membranes have been introduced by manufacturers with the intent of mitigating dermal exposure to smoke and soot on the face and neck. The introduction of these novel protective hoods caused the NFPA committee on protective clothing for structural firefighters to add test methods and performance requirements for particulate filtration efficiency and thermal burden to the protective hood specifications in the 2018 revision of the NFPA 1971 standard.

Objectives and Experimental Methods
The main goal of the presented research is to develop a fundamental understanding of the impact that the addition of particulate blocking layers into protective hoods can have on the overall performance characteristics of the hood. This holistic assessment of protective hood performance includes both material and head form evaluations of thermal flashfire protection, radiant protection, thermal burden and heat loss, and particulate protection.

Figure 1. Deposition of aerosol particles with standard knit protective hood
The material-level evaluations were conducted according to the test methods specified in NFPA 1971. Additionally, the product-level assessments of protective hood performance were conducted utilizing manikin head form test platforms (Figure 2) at NC State University’s Textile Protection and Comfort Center (T-PACC). The research project also included evaluations of the care and maintenance of traditional protective hoods compared with particulate blocking hoods regarding material durability following laundering and development of novel inspection methods for firefighters to determine the integrity of their hoods in the fire house.

**Preliminary Results**

As this is an ongoing project, the preliminary results show that although the inclusion of some particulate blocking layers into the protective hood adds filtration capabilities and noticeably increases the thermal protective performance, these benefits come at the expense of decreased heat loss and increased thermal burden. Additionally, the cost of currently available particulate blocking hoods is in the range of 230-500% (~$100-$180) more than a traditional non-particulate blocking hood (~$30) which is of concern for firefighters and departments regarding the durability of the more expensive product. Two different types of inspection methods, a light-based approach and a smoke penetration-based approach, have been developed to allow firefighters to easily evaluate the integrity of the particulate blocking layers throughout the duration of use.

**Acknowledgement**

This study was funded by the Fire Prevention and Safety (FP&S) Grants which are part of the FEMA Assistance to Firefighters Grants (AFG) Program.

**Keywords:** Firefighter, Protective Hood, Particulate, Thermal Burden, Thermal Protection

**References:**

Introduction
Firefighters rely on Personal Protective Equipment (PPE) for protection from heat, radiation, and exposure to chemical and biological agents. While PPE serves to protect the wearers from serious personal injury and even death, recent statistics suggest that more firefighters die or are injured from heat stress due to the inadequate metabolic heat dissipation than environmental heat exposure in the line of duty (1). Furthermore, the increasing number of cancer mortality and cancer diagnoses for firefighters has become a long-term health concern. This is likely due to their repeated and prolonged overexposure to toxic chemicals (1, 2, 3, 4). New studies indicate the neck and up-jaw are the least protected and yet most absorptive areas when firefighters repeatedly perform duties during fires and overhauls (5, 6). To mitigate metabolic related heat stress and smoke particulate overexposure, a nano based nonwoven material is developed featuring DuPont™ Nomex® Nano technology. The nano is an inherently flame-resistant material with a high LOI (Limited Oxygen Index). With the superior high surface area-to-volume ratio, this material exhibits ultra-light, ultrathin, and highly breathable characteristics with incomparable convective and radiant heat resistance. The first objective of our study is to understand if the nano material can help to reduce bulkiness and improve comfort when it is used as thermal liner in a turnout gear while still maintaining thermal resistant performance. The second objective of this study is to demonstrate if toxic smoke particles may be dramatically blocked by the nano material when being used as a barrier in a conventional hood.

Experimental
A typical thermal liner of a turnout gear is made of three layers. To investigate the benefits of nano material in relation to thermal resistance and comfort performance, the middle layer of a conventional thermal liner was replaced by a layer of nano material. The resultant turnout gear was then evaluated against a gear that contains a conventional thermal liner. Additionally, the blocking performance to smoke particles using the nano material as a barrier in a conventional hood was also investigated by analytical methodology in the lab and in the field when comparing a typical hood used by firefighters today. Durability of particle barrier hoods after multiple dons and doffs, multiple washes were also examined.

Results
The turnout gear using the nano material has shown to reduce the entire thickness by 20%, resulting in improved THL (Total Heat Loss) by 30 units, or 10%. Because of the reduction in bulkiness, turnout gear with the nano thermal liner showed faster drying time, lighter weight, and improved ergonomics without compromising Thermal Protection Performance (TPP) (Figure 1). In addition, the hoods using the nano material demonstrated a 4X reduction in the penetration of particles smaller than one micron with an increase in thermal protection by minimum 25% (Figure 2). Such smoke particle blocking performance has been further validated by field tests as well as fire departments. The outstanding breathability and particulate blocking performance were ranked highest by firefighters from multiple wear trials. Finally, the durability and functionality of particle barrier hoods has also been demonstrated after 250 times of dons and doffs, as well as 150 times of washes.
**Keywords:** Nano, firefighters, particles, PPE

**References:**
6. Monte Johnson P., Elizabeth Easter P., and Horstman S. W., Department of Agriculture at University of Kentucky, “Personal Protective Equipment for Pesticide Applicators”, 2000, pp 2
TECHNICAL REQUIREMENT ANALYSIS OF PERSONAL PROTECTIVE EQUIPMENT UNDER COMPLEX DISASTER ENVIRONMENTS

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Abstract
There are high requirements on the personal protective equipment (PPE) with the frequent occurrence of complex disasters. A lot of current PPE is difficult to meet the protective requirements in the complex environment, resulting in a large number of casualties [1]. It is necessary to analyse the multi-directional technical requirements of PPE under the complex disaster environments, including the following three aspects. The technical roadmap is shown as Fig.1.

1. Through the data analysis and case survey of disaster number and affected level, technical requirements of PPE are studied for the different disaster situations in the process of emergency rescue and risk disposal. It shows that high temperature, fire smoke, hazardous chemicals accidents, explosive shock and other disaster environments have each typical injury mechanism. The PPE to meet the requirement of the above disaster environments are reviewed and compared with the international protection requirement standards.

2. Through the literature research [2] and interviews with first-line rescuers, the key parts of the current PPE, are summarized including equipment selection and protection principle for complex disaster environment, and protective and comfort performance improvements.

3. Through the analysis of technical standards and dialogue with PPE research institutions, the development trend of PPE are obtained in some scopes, such as disaster environment, damage mechanism, protective material, type structure, and technical index.
Fig. 1. Technical roadmap of requirement analysis of PPE under complex disaster environments

Acknowledgement
This study was supported by National Natural Science Foundation of China (Grant No. 51706123), National Key R&D Program of China (Grant No. 2016YFC0802801 and 2016YFC0802807).

References
“PROSAFE; NEXT GENERATION OF PROTECTIVE GARMEN FOR CBRN PROTECTION”

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Introduction
Nowadays CBRN protective garments consist of a single layer of active carbon (AC) material embedded between two textile layers. When exposed to contaminated atmosphere, the hazardous gases transported in the air are adsorbed onto the AC material. The resulting cleaned air is free to stream through the protective clothing, assuring ventilation and thermal comfort to the soldier. When the AC becomes saturated it results in a total loss of the filtering capabilities. In order to extend the useful life time of the garments and the protection degree, two strategies can be used: i) to introduce a denser layer of AC and ii) embedding this filter material into lower permeability textile layers. However, both strategies results in lower air permeability of the protective clothing, leading to undesired higher heat stresses on the soldier. Such contradictory requirements make the right balance between high protection and acceptable ventilation difficult to achieve. PRO-SAFE project has implemented a totally different approach. Nanofiber-based polymeric membranes (NFM) and modified AC. Moreover, Quantum Dots (QDs) have been supported on NFM layers in order to improve the conform and provide new functionalities. QD’s are metal sulfide or graphene based particles with nanometric size (tens of atoms). PRO-SAFE is using QD’s properties to introduce new functionalities to the developed textile. i) QD’s change their colours by interacting with the CBRN agent adsorbed on their surface, thus when the multilayer composite of NFM-AC becomes saturated with CBRN the QD’s will change its colour, the change of colour have been detected by coupling a miniaturized UV-visible spectrophotometric detector to the garments structure. ii) QD’s photocatalyse the oxidation reaction in presence of UV-visible light, this phenomenon is used to degraded the NBQ after the end life of the garments, making the garments reusable. High protective performance with low burden, control of the saturation degree are the properties that have been achieved.
The activities carried out in the Project were focused on 3 different field related among them:

- Development of the nanofiber membranes loaded with QDs.
- Study of the interaction between QDs and different warfare agents, and relationship between warfare agents concentration and luminescence intensity.
- Study of the QDs influence in the warfare agents photodegradation, applying UV light.

- Development of the portable system able to measure the luminescence of the QDs loaded into de nanofiber membranes.
- Development of a wearable system to measure the temperature and the humidity inside the CBRN suit.
- Development of a communication system to control in a real-time and remotely the conditions of the CBRN suit.
Results

RESULTS OBTAINED

It has been obtained the nanofibre membranes loaded with different QDs by electrospinning technology.

QDs luminescence and the warfare agents influence in this luminescence has been used to quantify the warfare agents.

It has been analysed the capacity of the QDs to photodegrade the warfare agents in different conditions.
A portable detection system with high sensibility able to measure the QDs luminiscence has been developed.

A wearable prototype to measure the temperature and humidity inside the CBRN suit have been developed.

The communication system developed allows the data transfer by local network or by internet, this make possible the remote monitoring of the parameter selected.

The membranes carried out in the project reach up to 100 cm of water permeability with the same level of breathability.
PERFORMANCE EVALUATION OF THE PERSONAL PROTECTIVE CLOTHING: INDOOR CHEMICAL EXPOSURE MODELING AND TRANSDERMAL UPTAKE CALCULATION

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Abstract

Introduction: Protection against the hazardous chemicals is compulsory for the firefighters and emergency rescuers in accidents such as wildfire, blasting and leakage. In order to assess the performance of the personal protective clothing (PPC) under harmful environments, it is necessary to first simulate and analyze the exposure concentration and exposure time of the human body, second to quantify the absorption dose though the clothes and skin into the blood.

Method and Results: In this work, the CFD software ANSYS Fluent (Version 18.0.0) was employed to simulate the transient flow field of the indoor gaseous pollutants after the leakage accident [Luo et al., 2017]. The manikin model used in this case study has 16 segments whose surface areas correspond to a widely used thermal manikin. The exposure concentration for each segment was calculated during the simulation. The results of the gas concentration near the oronasal were used as the initial and boundary conditions for the respiratory CFD modeling.
[Xu et al., 2017]. Besides, a model of transdermal uptake of hazardous chemicals raised by Morrison et al. [Morrison et al., 2017] was employed in this case study, to model the diffusion of the gaseous pollutants within the cloth and skin. The diffusion process was modeled through four layers, namely cloth, skin surface lipids (SSL), stratum corneum (SC) and viable epidermis (VE), before the gaseous chemicals entered the blood. The final results of the absorption doses in blood were compared when the manikin was naked, wearing one-layer cloth and wearing two-layer cloth, respectively.

**Conclusions:** The study outcomes will raise the framework of the indoor pollutants exposure modelling and the potential human health injuries assessment in a chemical leakage environment, which are expected to generate the strategies to assess and improve the performance of PPC under emergency rescue. The methods in this case study will also be integrated into an online software developed by our institute recently.

**Keywords:** hazardous chemicals exposure, CFD, absorption dose, skin, personal protective clothing

**References:**
ANALYZING THE EFFECTS OF WASHING PROCESSES AND WEAR ON FABRIC FRICTION SOUND OF SOLDIERS UNIFORMS

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Introduction
The noise generated by fabric-to-fabric friction in the frame of military applications is essential to be studied in order to improve acoustic stealth (1) or estimate the ageing of the garment. Indeed, when a person is moving or walking, sounds are generated by the friction under arms or between legs. The sound properties of fabrics depend on many parameters like the weave patterns or the surface roughness (2). In addition, for garments, the repeated washing processes and its natural wear will gradually modify the surface of the fabric and therefore the fabric friction sounds. The aim of this study is to analyze the influence of wear and washing processes on fabric friction sound.

Experimental
In the scope of this study, three groups of parameters are measured, acoustic parameters, mechanical properties of the fabric and sensory parameters. The acoustic parameters especially the total noise level are measured with an experimental device which simulates the human arm motion during walking (3), the mechanical properties are obtained thanks to the Kawabata Evaluation System (4) and a sensory panel is used for the last group of parameters. Some of the parameters are linked by some positive or negative correlations. In the following paragraph, some results of correlations are given. Two sets of fabrics are used; one is composed of samples worn out by abrasive cycles thanks to Martindale abrasion tester (5) and the other one of samples washed many times.

Results
Visual and tactile differences are noticeable, degradation of the color is observed and the surface of the fabric becomes smoother. The ageing of fabrics induces necessarily a change in the surface’s condition and in fabric friction sounds. According to the evolution of total noise level (Figure 1), three domains can be observed and analyzed thanks to a Principal Component Analysis (PCA). An example of PCA is represented in Figure 2, some correlations between acoustic and mechanical properties of the fabric can be observed in the domain corresponding to 0 from 5,000 abrasive cycles.
Therefore, measuring the total noise of friction sound of a garment could be a new method to assess the wear of fabric.
Figure 1. Evolution of the total noise level as a function of number of abrasive cycles

Figure 2. Correlation between mechanical properties and sound parameters of worn out fabrics

References
AIR GAP MEASUREMENT IN FIREFIGHTER CLOTHING
BY A 3-D BODY SCANNER AND ITS APPLICATION TO
HEAT TRANSFER ANALYSIS

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Introduction
For thermal resistance of firefighter clothing, there are bench top fabric test and flash fire manikin test which heat flux scenario is involved in flash fire. In the current thermal resistance test, evaluation for current firefighter clothing has been carried out by a fabric test where the cost of a test apparatus and a test piece is inexpensive and high repeatability. However, since the test piece is compressed with a copper calorimeter, there are little the air layer between fabric layers and the role of air gap which mainly used heat attenuation for firefighter clothing has been neglected. The flash fire manikin test can conduct thermal resistance based on the thickness of the air layer generated by the garment structure of each part of the body. However, development cost of prototype clothing and the mannequin system is so expensive, it is not practical for garment manufacturers. Therefore, by fabricating a structure which generates air layers between fabrics and existing fabric test, it is possible to reproduce the thermal manikin test result.

Experimental
To obtain the thickness of the air layer, a mannequin (Nanasai MD-20A) and a Japanese firefighter clothing were used. The manikin size is the average human body size of Japanese 20’s male obtained from 1992 to 1995. The firefighter clothing was disassembled into three layers (outer layer, moisture barrier and thermal liner) and pocket and reflector were also removed. Using a 3D body scanner (Hamamatsu Photonics C 9036-02), the scan was carried out by changing the wearing condition by overlapping with the naked body, the thermal liner, the moisture barrier, and the outer layer. The thickness of the air layer was generated by sandwiching a silicon sheet (Tigers polymer SR sheet) having thicknesses of 0.5, 1.0 and 2.0 mm between cloths fixed with a sample holder. The transmitted heat through air layers and fabrics was evaluated using a copper calorimeter according to ISO 9151[1]. Temperature measurement was carried out on both sides of the fabric of each layer, mainly using T type thermocouple (Omega Engineering φ 0.157 mm), and K type thermocouple (Omega Engineering φ 0.157 mm) was used when the heat flux was 20 kW/m². The thermocouple was embedded and measured between the center of the heating surface and the diameter of 5 mm. Heating of the cloth was conducted by radiating heat of 10 kW/m² and 20 kW/m² perpendicularly to the heating surface of the sample holder with a cone heater conforming to ISO 5660[2].

Results
Figure 1 shows horizontal section data output from 3D body scan data. The thickness of the air layer of each part was measured by dividing the upper half of the body into six places: Shoulder, Chest, Elbow, Waist, Hip, and Arm. Figure 2 shows the air layer thickness of each part. From the results, it was found that the air layer between the human body and the heat shielding layer increased from the shoulder to the hip, and the total thickness of the air layer increased accordingly. Also, the air layer beneath the moisture barrier was relatively small (0 mm to 6 mm) at any site, mainly composition of an air layer were beneath the thermal liner and the outer
layer. It was also found that the structure of the air layer of the arm was completely secured by the air layer beneath thermal liner and without any air layer beneath the moisture barrier. Measurement of the temperature change of the copper sensor installed under the thermal liner was conducted and the index HTI12 and HTI24 were analyzed. Those indexes assume pain on the skin and causing the second-degree skin burn defined in ISO 9151[1], respectively. Figure 3 shows the indices when heating heat flux was 20kW/m². Relative to the absence of air layer (No Air Gap), the shoulder was about 2.5 times higher, and about 5 times higher at the waist. Since the current fabric standard test was conducted without the air layer, it is obvious that the current fabric test differs from the condition where the air layer is provided. The value of the HTI increases with the same tendency in the part where the air layer of the torso is increasing. The HTI of the hip where the air layer is relatively small and the arm without the air layer under the surface layer were similar. It was found that the burning rate depends not only on the total thickness of the air layer but also on the internal configuration of the air layer.

<table>
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<th>Arm</th>
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<td><img src="image" alt="Cross section view by 3D body scanning" /></td>
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**Figure 1.** Cross section view by 3D body scanning

**Figure 2.** Result on air gap size measurement.

**Figure 3.** Heat transfer index (HTI) with and without air gap at different body parts.

**Acknowledgement:** This work was supported by JSPS KAKENHI Grant Number JP15H01789 and JP16H03133.

**Keywords:** Temperature measurement; Air gaps; 3-D scanning; Heat transfer index; Manikin test.

**References**

PROTECTIVE CLOTHING AGAINST COLD – IMPACTS OF THE STANDARD REVISION

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Introduction
The revised cold protective clothing standard (1) includes many positive changes that allow improving accuracy and reliability of the insulation measurements. Other changes may overcomplicate the cold protective clothing ensembles’ evaluation without intended effect. The present paper focuses on the changes that are connected with resultant effective thermal insulation ($I_{cler}$) assessment, and only minimally covers the other aspects.

The impact of changes
The new standard has narrowed down the possibility of testing and calculation methodology choice. By the revised standard only walking tests are allowed. Standing (static) tests with calculating walking values is not included any more. However, the dynamic values cannot be used directly in recommended cold exposure evaluation and risk assessment and management algorithms, e.g. according to ISO 11079 (2). There are well defined equations available for standard type industrial cold weather clothing allowing calculations from static to dynamic (considering the effects of wind and walking) conditions (3, 4). More research must be carried out on other types of clothing design for developing as reliable relationships, while the standard test methods should be as simple as possible, and easily understandable and applicable.

The variation is further diminished by allowing only parallel calculation model compared to the earlier version (5) that allowed also serial model (4, 6, 7) or the use of average values of both. The reference values of standard garments and values in Annexes’ tables were updated in order to reflect this change.

In the revised standard, a third set of clothing (C) was added to the available calibration ensembles A and B (8). C covers the higher end of the cold protective work wear. Improved basis for calibration together with strict definition of test methodology and calculation model, inter-laboratory variability will be diminished further.

The revised standard has included a requirement for pre-treatment according to manufacturer’s cleaning instructions, e.g. 100 times washing if manufacturer claims that the garment can be washed 100 times. If cleaning is not defined then five washing cycles should be carried out before measuring insulation on manikin.

However, all that extra time and investment will be reflected in the product price. This cost may affect small and medium sized companies’ business if they produce special clothes for specific occupational groups in relatively small patches. Even the specific occupational groups, sometimes small, but often important for functioning of the society in any weather conditions, may get it worse, if they cannot afford specially designed cold protective clothing any more.

The literature on effects of washing on clothing insulation is contradictory showing both reduction and increase (9-11). No change or increase can be related to a missing wear phase (9, 11). Here the research should find relevant, but less time consuming and costly methods of testing the effects of use and care on cold protective garments.

Conclusions
The accuracy of the method has been improved by fixing the improved basis for calibration, calculation model and measurement mode. However, adding washing may also introduce an
adverse impact on protection use in practice as a side effect. Research and targeted funding is needed in the area to address such possible problems long before a standard is sent for voting.

**Keywords:** insulation; test method; static; dynamic; manikin; calculation mode; calibration; clothing ensemble; pre-treatment; washing cycle

**References:**


AN AUTOMATED CONTROL SYSTEM FOR TESTING RESISTANCE OF PROTECTIVE CLOTHING MATERIALS TO PENETRATION BY LIQUIDS UNDER PRESSURE

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Introduction
There are several international standards that address the resistance of chemical protective clothing materials to the penetration by liquids [1]. The hydrostatic pressure has been documented to discriminate between protective clothing material performance and correlate with visual penetration results that are obtained with human factors validation. The same methodology, based on hydrostatic pressure equipment, is referenced also in other standards addressing penetration resistance of protective clothing materials against synthetic blood or blood-borne pathogens. These standards [2] use Phi-X174 Bacteriophage as surrogate which simulate viruses such as Hepatitis B, Hepatitis C, and HIV.

As several standards use the same test protocol methodology, in this study we present a control system (Figure 1) that integrates several regulations that evaluate the resistance of protective clothing materials to penetration by liquids under pressure. The developed system allows the user to select in the hydrostatic pressure equipment a specific test method and automatically sets a stepped pressurization protocol to test the clothing material.

Experimental
By means of the developed system, the penetration of synthetic blood was assessed through clothing and gloves materials. The test method selected for the experimental part from the 5 possible penetration methods and protocols available in the test equipment, was ISO 16603 [3], method B. In some of the tested materials, holes were intentionally performed with needles with different gauges.

Results
In this work, an automatic system for testing the resistance of protective clothing materials to penetration by liquids under pressure was presented. The results indicate that the developed system facilitates laboratories the application of test methods used to evaluate the barrier effectiveness against liquids of materials used for protective clothing. The fluid pressure is modified according to the standard used and remains constant during a specified amount of time. Thus, the developed system allows the selection of a specific test method and automatically sets a stepped pressurization protocol to the clothing material, increasing in this way the accuracy in the application of the aforementioned test methods. The capacity of pinhole detection in gloves was evaluated according to the test method selected. The results were compared with those obtained with the water leak test method described in EN ISO 374-2 [4].
Keywords: Protective clothing, fluid penetration, virus, hydrostatic pressure, synthetic blood

References:
1. ISO 13994 (2005) Clothing for protection against liquid chemicals -- Determination of the resistance of protective clothing materials to penetration by liquids under pressure
2. ISO 16604 (2000) Clothing for protection against contact with blood and body fluids -- Determination of resistance of protective clothing materials to penetration by blood-borne pathogens -- Test method using Phi-X174 bacteriophage
3. ISO 16603 (2000) Clothing for protection against contact with blood and body fluids -- Determination of the resistance of protective clothing materials to penetration by blood and body fluids -- Test method using synthetic blood
STUDY ON THE EVALUATION METHOD OF PROTECTIVE EFFECT OF INDIVIDUAL PROTECTIVE EQUIPMENT BASED ON HUMAN MODEL

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Introduction
With the increasingly severe global anti-terrorism situation, public security organs are paying much more attentions to the safety and reliability of individual protective equipment. In view of the current situation like diversified types, wide sources and uneven quality of individual protective equipment, it is more and more important to evaluate the effectiveness and difference of the equipment by a quantitative way, thus accurately evaluating the injury effect of kinetic energy and explosion shocks. An evaluation scheme of individual protective equipment based on human model is proposed in this paper.

Experimental
The scheme establishes a platform which integrates human model, menaces (for example, the explosive, projectile, et al), sensors, data acquisition equipment, high-speed photography system, power supply system and so on to realize the evaluation of protective effect to the equipment through the analysis of the data and images in several tests (Figure 1).
In this platform, three key parts including head, neck and chest of the human model are equipped with corresponding sensors, which can complete 16 channels of data acquisition, realize image acquisition of 1 million frames per second, and synchronize, accurately capture and analyze the mechanical response values brought about by the kinetic energy impact of the projectile and the blast impact of the explosive, thus providing a basis for the evaluation of related equipments.

Results
Based on this evaluation platform, it is possible to not only measure the bulletproof capability of body armors and helmets, but also determine the safe bullet velocity, distance and body injury condition, to compare the protective performance of similar individual protective equipments, explore the law of injury effect of different weapons and reveal the protection mechanism of individual protective equipments. For the equipments such as explosive searching suit, bomb disposal suit, anti-riot suit and even explosion-proof boots, the platform can help to set up a scientific explosion test matrix, to measure the parameters of velocity, acceleration, pressure, impact, action time, on the human model’s head, neck and chest, and accurately describe the degree of mechanical response and damage of human body under the blast of the explosive. Besides, it can accurately determine the protection equivalent and the safe use distance, evaluate the protection capability, and compare the difference of similar products to guide the design and production of the individual explosion protection equipments.
Acknowledgement
The work is supported by the National Key Research and Development Program of China (Project No. 2016YFC0802805)

References:
MEASURING AND PREDICTING THERMAL RESISTANCE OF COLD-WEATHER CLOTHING CONFIGURATIONS

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Introduction
During cold-weather activity, the environment can impair a person’s physical performance and increase the risk of cold injuries such as frostbite and hypothermia. Appropriate cold-weather clothing is necessary for optimal performance and protection from cold injury. Thermal manikins have been widely used to evaluate the thermal performance of clothing and individual equipment (CIE), including cold-weather ensembles [1, 2]. Thermal resistance is often used as input to thermoregulatory models to determine the level of cold protection [3]. Typically, thermal resistance is measured on a thermal manikin for a specific configuration of CIE, and the results are not applicable if the configuration is altered. As an alternative to performing thermal manikin testing for all possible CIE configurations, the US Army Research Institute of Environmental Medicine (USARIEM) is developing a new method of testing individual layers of a multi-layer clothing system and predicting thermal resistance of any configuration from the individual layer values. For this study, cold-weather clothing configurations were selected from the individual layers of the clothing system, thermal resistance was mathematically predicted, and the results were compared with measured values.

Methods
Thermal resistance values of cold-weather clothing were measured on a thermal manikin according to ASTM F1291-16 [4]. Six layers of the clothing system were tested individually. Additionally, six ensembles consisting of a combination of the six layers were tested on the thermal manikin: configurations A, B, C, D, E, and F. The effective thermal resistance was calculated by subtracting the thermal resistance of the boundary air layer of a nude manikin from the thermal resistance of the clothed thermal manikin. An equation by Olesen was modified and used to predict the thermal resistance of the various ensembles based on the measured values of individual layers [5]. The predicted effective thermal resistance values from the new equation were compared to the measured effective thermal resistance for the six clothing configurations.

Results and Discussion
The measured and predicted effective thermal resistances are shown in Table 1. Measured results varied from 0.133 to 0.290 m²K/W while predicted results varied from 0.115 to 0.351 m²K/W. There was an average difference of 11 % among all six measured and predicted resistance values (range: 2.8 % to 20.9 %). Four out of the six prediction values were within 12 % of the measured values. This showed that the predicted values using the revised Olesen equation were acceptable for some configurations, but not all. Therefore, it is necessary to develop new prediction equations. Specific equations for distinct categories of clothing (e.g., cold-weather clothing), or separate equations to predict thermal resistance for distinct regions of the body (e.g., torso, hands) are potential ways to improve accuracy, but more testing and analysis will be required to confirm that these options predict thermal resistance of ensembles sufficiently.
Table 1. Measured and predicted thermal manikin results for various cold-weather clothing configurations

<table>
<thead>
<tr>
<th>Effective Thermal Resistance, $R_{cle}$ (m²K/W)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>0.133</td>
<td>0.169</td>
<td>0.177</td>
<td>0.203</td>
<td>0.290</td>
<td>0.290</td>
</tr>
<tr>
<td>Predicted</td>
<td>0.115</td>
<td>0.188</td>
<td>0.182</td>
<td>0.227</td>
<td>0.351</td>
<td>0.275</td>
</tr>
<tr>
<td>% Difference</td>
<td>-13.8%</td>
<td>11.4%</td>
<td>2.8%</td>
<td>11.6%</td>
<td>20.9%</td>
<td>-5.2%</td>
</tr>
</tbody>
</table>

This new method aims to reduce the amount of thermal manikin work needed through the use of prediction equations based on thermal resistance measurements of individual clothing layers. Additional benefits of this method include the ability to compare clothing layers that perform the same function and determine which clothing system has the component with the best thermal resistance properties. This method will also provide the ability to substitute the thermal resistance properties of new CIE after thermal manikin testing has been completed for a particular clothing system. The current level of variability between predicted and measured values using the current equations demonstrates the need for further improvement. Additional testing with other multi-layer clothing systems will need to be completed and new prediction equations will need to be developed.

Acknowledgement
Approved for public release. The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or reflecting the views of the Army or the Department of Defense. Any citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

Keywords: thermal manikin, hypothermia, frostbite, protective clothing.

References:
CLOTHING AND OCCUPATIONAL HEAT STRESS ACROSS EUROPEAN INDUSTRIES IN HOT CLIMATES

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In occupational settings, clothing has practical and protective functions that is prescribed by tradition or labor safety regulations. However, clothing can also influence human thermoregulation, which is important both for the workers’ health and for productivity. Although clothing in some scenarios may protect against solar radiation, it also increases resistance to heat loss from the body to the environment. For workers with an elevated endogenous metabolic heat production and in a hot climate, this is an important issue as it will hamper the ability to remain productive and prevent heat-induced illnesses. The present study provides preliminary data from an ongoing EU H2020 project (www.Heat-Shield.eu) assessing thermal insulation and evaporative resistance of the prevalent clothing, and heat strain reduction by ventilation clothing intervention.

The thermal insulation and evaporative resistance of the clothing worn by workers across European industries were estimated using International Standard methods [1] and/or measured on a thermal manikin (Table 1). In addition, intervention studies with ventilation clothing were conducted on field study personnel and agricultural workers. Environmental conditions were measured using standard WBGT equipment and workers metabolic rate were either estimated from time-motion analysis, observations or calculated on the basis of individually reported work intensities. The ventilation clothing used in the intervention studies was re-designed from previous studies [2], using a short sleeve garment with two battery driven fans placed at both sides of the waist. Ventilation holes were designed and vertically aligned along the middle upper back. This ventilation design to fit to the body mapping of local sweat rates [3] was expected to provide improved convective and evaporative cooling effect at the spinal region.

Table 1. Climate, work intensity and clothing used in European agriculture, manufacturing and construction sectors in July 2017. The thermal performance of the clothing were estimated [1] \( (R_{clo}=0.18 \times L_{cl}) \) unless otherwise specified.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Climate (WBGT), °C</th>
<th>Garment</th>
<th>Clothing insulation ( (L_{cl}) ), clo</th>
<th>Clothing evaporative resistance ( (R_{ecl}) ) or vapour permeability index ( (i_m) )</th>
<th>Work intensity (metabolic rate, W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>26.2-28.6 (measured)</td>
<td>T-shirt, shorts, underpants, socks, shoes</td>
<td>0.40 ( (0.53, \text{shorts}) )</td>
<td>( R_{ecl} = 7.2 ) ( i_m = 0.42 )</td>
<td>270</td>
</tr>
</tbody>
</table>
The preliminary results from representative field studies are shown in Table 1. For the intervention study, four males and one female wore the ventilation clothing during light intensity activities (standing and walking) inside a greenhouse (relative humidity 37.6-44.0%, air temperature 33.5-37.3 °C, WBGT 28.6 °C). The perceived overall thermal sensation (from very hot +4 to very cold -4), thermal comfort (from comfortable 0 to very very uncomfortable +4), and skin wetness sensation (from normal 0 to very wet +3.0) were recorded. The intervention effects from this study and similar outdoor intervention with two agricultural workers are shown in Fig. 1 and 2.

In conclusion, clothing is mainly flexible and with lower thermal insulation and evaporative resistance in the agricultural sector compared to the manufacturing and constructive sectors where protective clothing are commonly used, adding additional thermal insulation and evaporative resistance to heat dissipation. However, ongoing clothing intervention studies have identified that thermal insulation and evaporative resistance may be reduced without compromising safety regulations. Enhancing ventilation to facilitate evaporative cooling may improve thermal sensation and thermal comfort. These preliminary results indicate that clothing optimization is a considerable factor that may be of great importance for heat stress mitigation in industrial settings where workers are exposed to elevated heat stress due to climate change.

Acknowledgements
This work was financed by the European Union’s Horizon 2020 research and innovation programme (HEAT-SHIELD) under grant agreement No 668786.

Keywords: hot climate, clothing insulation and evaporative resistance, ventilation clothing, intervention.
References:
HEAT STRAIN IN CHEMICAL PROTECTIVE ENSEMBLES
WITH DIFFERENT MATERIALS

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2US Army Natick Soldier Research, Development & Engineering Center

Introduction
An ongoing challenge in material science has been to reduce heat strain experienced by individuals wearing chemical/biological (CB) protective ensembles (1, 2). However, improvements in thermal properties (thermal and evaporative resistances) of CB protective materials have not always resulted in a significant reduction in heat strain of ensembles. The objective of this study is to analyze the relationship between the thermal properties of eight protective fabric composites and heat strain in eleven protective ensembles constructed with those fabrics.

Methods
The eight materials consist of seven prototype CB protective materials and one traditional material (baseline). Each of the twelve ensembles included typical CB protective or regular clothing, which is made from a single material with other protective equipment, e.g., mask, gloves, overboots and body armor. The fabric samples were tested on a sweating guarded hot plate to measure fabric thermal and evaporative resistance. The ensembles were tested on thermal manikins to measure ensemble thermal and evaporative resistance. All the tests were conducted according to ASTM standard procedures and conditions (3).

These ensemble thermal and evaporative resistances were used as inputs to thermoregulatory models that predict human thermal responses to various combinations of physical activity and environmental conditions. Heat Strain Decision Aid (HSDA) of the US Army Research Institute of Environmental Medicine (3, 4), an empirical model, was used for the simulation. It predicts core temperature, maximum work times, water requirements, and likelihood of heat casualties. The inputs were: height (1.77m), weight (81.3 kg), metabolic rate (400W), ensemble thermal and evaporative resistances, and three environmental conditions: temperate (20°C, 50 % RH, 2 m/s wind speed), jungle (30°C, 75 % RH and 2 m/s) and desert (40°C, 20 % RH and 2 m/s).

Results and Discussion
The fabric thermal and evaporative resistances ranged from 0.01 to 0.05 m²·°C·W⁻¹ and from 3.84 to 12.82 m²·Pa·W⁻¹, respectively. Ensemble thermal and evaporative resistances ranged from 0.16 to 0.29 m²·°C·W⁻¹ and 27.05 to 65.15 m²·Pa·W⁻¹, respectively. Material properties contribute ~11% of the thermal resistance and ~15% of the evaporative resistance of the eleven multi-layer ensembles tested.

As shown in Figure 1, predicted endurance times are affected by swatch thermal and evaporative resistances, but the magnitude of these effects are dependent on environmental conditions. Heat strain is affected more by evaporative resistance than thermal resistance. Endurance times varied from 170 to 300 min under temperate conditions while endurance times varied from 90 to 170 min under desert and jungle conditions. At the latter two conditions, endurance times among the nine ensembles were almost identical and varied only from 90 to 100 min although their fabric thermal and evaporative resistances were different and ranged from 0.01 to 0.05 m²·°C·W⁻¹ and 6.0 to 13.0 m²·Pa·W⁻¹, respectively. Therefore, the benefits of improved fabric thermal properties on endurance times may only be observed under certain
environmental conditions. It is important to explore all possible options both on a material level and at the system level to maximize the potential to reduce heat strain.

Figure 1. Effect of fabric thermal/evaporative resistance on predicted endurance times at 400W metabolic rate for eleven ensembles with different material in temperate, jungle and desert conditions.

Acknowledgement
Approved for public release. The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or reflecting the views of the Army or the Department of Defense. Any citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

Keywords: heat strain, protective clothing, manikin, modeling, thermal properties

Reference:
NUMERICAL STUDY OF PHYSIOLOGICAL RESPONSES OF HAND IN COLD ENVIRONMENT

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Introduction
Gloves, boots, and helmets as subsystems in personal protective equipment (PPE) are critical in response operations for firefighters and soldier to ensure their safety and health. Gloves, in particular, have drawn significant complaints from fire service due to the insufficient protection and decreased manual performance. The hands or fingers are among the most vulnerable locations of the human body to suffer cold injuries due to a greater surface to mass ratio, low metabolic rate and large change in blood flow [1]. Most studies on hands and fingers protection focused on the particular types of gloves with specific conditions and therefore the understanding of the fundamentals among glove thermal comfort properties, environmental conditions, and hand physiological responses is very limited. In response to these challenges, a numerical hand-specific model based on the heat and mass transfer in the hand-glove-environment system and thermoregulation mechanism was developed to simulate physiological responses of the fingers, palm, and dorsal. The proposed numerical model was compared with data from sweating hand and human trial tests, and it is expected to predict physiological responses and cold stress. The model can provide fundamental data for protective glove development and engineering, which could enhance human health and safety, specifically the industry workers and military personnel.

Methods
The hand thermal model was approached by divided the human hand into 16 segments. Each segment of the hand was comprised of core, muscle, fat, and skin layer. The central blood compartment exchanged heat with all other nodes through convection. From the modelling perspective, the proposed model was comprised of three systems: 1) the passive system, which predicted the heat transfer within the hand and that between the hand and its thermal environment via radiation, convection, and evaporation, 2) the active system, which calculated the thermoregulation through shivering, sweating, vasoconstriction, and vasodilation, and 3) the clothing system that simulated the heat and mass transfer through the fabric layer. The radius and length of each finger were measured from a sweating hand system, and then the volume of each finger was calculated. The heat balance of each segment was obtained from the human thermal model from our previous study [2].

Results and discussion
To validate the performance of the proposed model, the surface temperatures from fingers, palm, and back were predicted with a glove with the thermal resistance of 1.11 clo, which were the same as these in the work of Candas et al. [3]. Comparisons of skin temperatures between the simulations and measurements were displayed in Fig. 1 (a) Thumb and fingers, (b) Palm and back.
The results indicated that the proposed model could predict the skin temperature at the thumb, fingers, palm, and back of the hand in trend. The discrepancies of skin temperature between simulated results and measured ones might be caused by the work intensity of the human, thermal properties of the glove (e.g. evaporative resistance), and the inter-individual variations which significantly affect the skin temperature. The proposed hand-specific model provides fundamentals of hand and its heat transfer associated with wearing gloves. It will part of the systematic tool for next generation glove development.

References:
HYDRODYNAMICS OF HOT WATER FLOW ON HORIZONTAL FABRICS AND ITS INFLUENCE ON THERMAL PERFORMANCE OF FABRIC SYSTEMS

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Introduction

Firefighters and industrial workers can be exposed to emergency conditions in their occupational environments. They may sustain burn injuries which can be caused by exposure to hazards such as exposure to hot liquids and pressurized steam used extensively in industry. Protective clothing is the only barrier between the skin and these thermal hazards. The flow of hot water on protective clothing may cause heat to be transferred through the protective clothing and cause skin burn injuries. As such, the understanding of the hydrodynamics of the hot liquid flow on fabrics provides a useful tool in understanding of local heat transfer caused by hot liquid flow on the fabric. Hydrodynamics of liquid flow on horizontal and inclined surfaces, and jet impingement heat transfer have been subjects of extensive research (e.g., [1-3]). However, hot liquid impingement on the surface of a fabric is different from hot fluid impingement onto a smooth rigid surface. Due to the interaction of water with fabric surfaces and the fact that water could penetrate the fabric structure, different features are expected in liquid flow patterns on fabrics. In this study, the hydrodynamics of a hot water jet impinging on horizontal fabric systems and the parameters which influence heat and mass transfer through the fabric system were studied, along with their effects on the thermal performance of the fabric.

Experimental

The fabric systems selected for this study represent thermal protective garments worn by firefighters and other workers. A modified apparatus (based on ASTM F 2701-08, Evaluating Heat Transfer through Materials for Protective Clothing upon Contact with a Hot Liquid Splash) was employed [4]. Fabrics were placed on a flat skin simulant plate with dimensions of 404x253 mm and exposed to water from a nozzle with 10 mm diameter. Twenty nine heat flux sensors which were mounted in the skin simulant plate, were used to observe the effects of the flow of hot liquid on thermal performance of the fabric systems. The data acquisition system recorded the temperature every 0.1 s, and the transmitted and discharged energy during and after exposure. A bio-heat transfer skin model was employed in conjunction with Henriques’ Burn Integral to predict second degree burn time [5]. A Canon digital camera and an FLIR InfraCAM SD thermal imager were used in order to take images of the water flow patterns and to investigate the temperature profile on the surface of fabrics.

Results

The results in this study were obtained based on fixed experimental variables such as hot water temperature (90°C), flow rate (80 mL/s) and nozzle-to-plate separation (z/d=9). Hot water was heated to a pre-set temperature and was sprayed on the fabric systems which were mounted on the sensor board and were taped flat. The water leaving the nozzle hit the fabric and flowed on the surface in a thin layer, and spread radially from the stagnation point. This region is referred to as the supercritical region in this study. As the radius of the supercritical region increases, the velocity of the liquid and Froude number decrease, the liquid film decelerates and gains potential energy which is followed by a sudden increase in the fluid height. This phenomenon
is termed a hydraulic jump. Analyses of the transmitted energy to the skin simulant as well as the predicted area of second degree burn reveal that the development of the hydraulic jump causes a significant decrease in the water temperature and heat transfer to the skin simulant. Therefore, the determination of the position of hydraulic jump or the area of the subcritical zone is a crucial factor in the evaluation of thermal performance of the fabric systems exposed to water.

The sudden change in the liquid height and the location of the jump depend on a local balance between fluid momentum and hydrostatic and surface tension forces [3]. As such, surface roughness affects the shape and location of the jump. The surface roughness of a fabric relates to the physical properties of its fabric structure such as fabric weave and surface finishing (intrinsic roughness). The roughness can also be referred to as unevenness of the fabric surface due to external forces such as inertial forces caused by the jet of water at the stagnation region or the supercritical area (extrinsic roughness). Analyses of the supercritical region area and the transmitted energy during exposure reveal that the increase in the roughness of fabric in the stagnation and supercritical regions affects the velocity of water in these areas. This results in a more unstable jump and a decrease in the amount of transmitted energy to the skin simulant plate. It appears that fabric thickness, fabric density and surface finishing and the resistance to water vapor diffusion affect the fluid momentum and hydrostatic and surface tension forces which influence the position of the hydraulic jump on the surface of the fabric.

In addition, fabrics usually have a porous structure and the jet of water can penetrate through the fabric. Enhancement of the resistance to water penetration through the fabric system reduces water penetration within the structure of fabric system. This phenomenon caused the thermal energy to be transmitted at a slower rate and a reduction in heat transfer to the skin simulant during exposure. For fabrics with excellent resistance to water penetration, when a hot liquid jet hits the fabric at the stagnation point, the water bounces on the surface of the fabric and some peaks in the absorbed energy curve are created in the supercritical region. However, in the permeable fabric, where the water penetrates into the fabric at the stagnation point, the peak of the absorbed energy is located in the stagnation region because the penetrating hot water may hit the skin simulant and the liquid sheet does not bounce on the surface of fabric.

The fabric may also gain thermal energy after the exposure. After the termination of exposure to hot water, the stored energy in the fabric discharges to the skin simulant and lowers the thermal performance of the fabric system. The discharged thermal energy was observed to be higher for the portions of the fabric that were positioned underneath the hydraulic jump and downstream from the flow in horizontal orientation.

Analyses of the area of the supercritical region, the transmitted and the discharged energy during and after exposure, and the predicted area of second degree burn confirm that that fabrics with excellent water surface resistance and excellent water penetration resistance (e.g., water penetration resistant fabric with hydrophobic surface) are predicted to provide the best performance when exposed to hot water among the studied fabric systems.

Key words: hydrodynamics, hot water flow, transmitted and stored energy, thermal protective clothing.

References:


EVALUATION OF “THE END OF SERVICE LIFE” OF SELF-HEALING MATERIALS APPLIED IN ALL-RUBBER PROTECTIVE GLOVES

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Introduction
Degradation and damage in polymer materials used in all-rubber protective gloves are a natural consequence of their use. Products may be affected by various factors reducing their mechanical or protective properties. These factors originate from the conditions at the workplace, the interaction between the user and glove as well as mechanical or chemical stress. It should be emphasized that the changes in glove properties cause the reduction of the time of safe use of protective barrier material, what is not easily identified by workers due to the micro-size of damages (1,2). Currently, self-healing polymer materials are examined to minimize economic loss and accidents in the work environment (3,4).

Experimental
The paper presents the results of mechanical parameters testing for self-healing elastomeric composite in the form of polymer film and composite reinforced with textile carrier. The method of mechanical interaction in conditions of simulated working environment such as puncture, cutting and abrasion was proposed. Damaged material samples were tested for self-healing ability. Moreover, glove mechanical resistance was determined by simulation of 8-hours operating mode. The effect of the damage on the mechanical properties of the materials before and after the self-repair process with reference to EN 388:2016 standard was analyzed.

Results
The obtained results confirmed that, it is possible to use these polymer composites with self-healing properties for all rubber gloves. Tested materials based on silicone rubber have comparable mechanical properties, with currently used butadiene-acrylonitrile rubber gloves. In addition, the tests also confirmed the correctness of the self-repair process, which was expressed by comparable mechanical properties to the initial values. “The end of the service life” cycle of the self-healing polymer for protective gloves is presented in Figure 1.
Figure 1. “The end of the service life” cycle of the self-healing polymer for protective gloves.

Acknowledgement
The publication is based on the results of Phase IV of the National Programme “Safety and working conditions improvement,” financed in the years 2017–2019 in the area of research and development by the Ministry of Science and Higher Education/the National Centre for Research and Development; Programme Coordinator is the Central Institute for Labour Protection – National Research Institute, Poland.

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5. EN 388:2016 Protective gloves against mechanical risks, The European Standard has the status of a Polish Standard.
A KNITTED FABRICS FOR PROTECTION AGAINST MOSQUITO BITES WITHOUT THE USE OF INSECTICIDES

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Mosquitos provide a large risk to people and have been designated as most lethal to humans. Previous research has shown what the requirements are for fabrics to prevent mosquitos from biting through fabrics. A newly designed series of knit fabrics with a superfine structure provides not only a very comfortable, breathable, material but also a bite-proof barrier to mosquitos. It provides a micro-scale level protection to human beings for reducing the risk of mosquito-borne diseases such as Malaria, Yellow Fever and Zika, without the use of insecticides. To better understand this relationship, the protective mechanism of the knitted fabric was analyzed and discussed in this paper, and its bite-proof capability was evaluated by an in vitro bioassay test based on fabrics with different pore sizes. In order to improve its bite-proof capability, two simple and promising methods were employed, and the results show an improvement in the bite proof performance of this knitted physical barrier at the micro-scale level. The approach to develop mosquito bite-proof barriers presented in this work has the potential to be extended to a variety of other newly designed bite-proof textiles. The research in this project focused on a specific species of mosquitos, Aedes aegypti, but the work can be expanded to other species as well. On the basis of proboscis dimensions, there is a critical pore size for the bite-proof fabric that is 25µm. In order to characterize fabric pore size and distribution, an optical microscope (Nikon, Eclipse 50i) was used. The bite-proof capability of this fabric was examined by ‘arm-in-cage testing.’ One hundred mosquitos, age 6-8 days were used in each test. The duration time of the tests was 10 minutes. Mosquitoes were observed landing on the fabric and taking a blood meal.

In Figure 1, the ray casting method was used to observe the pore distribution and pore size of the fabric. The white area are the pores in the fabric. From the image analyses, the density of pore distribution of both fabrics are similar and their different pore size is due to yarn count. The average pore size of Knit I and Knit II is 34.3µm and 27.7µm, respectively, which are both
larger than the diameter of the proboscis (25 µm). It means these two fabrics will fail to resist the penetration of the proboscis. Bioassay tests confirmed these result; reducing the pore size below the critical pore size will improve the bite-proof capability of textiles.

**Improved bite-proof capability**

Based on the results discussed above, there was a need to improve the bite-proof capability of the fabric by decreasing its pore size. Controlled heat setting was used to physically compress the fabrics.

![Figure 2](image)

**Figure 2.** Left panel: Pore size; middle panel: air permeability; right panel: bioassay test results of fabrics before and after treatment.

Figure 2(a) shows pore sizes of both fabrics were reduced, especially in Knit I. Figure 2(b) shows a significantly decreased air permeability of Knit I after heat set. In contrast, the air permeability of Knit II remains similar after washing. The arm-in-cage test demonstrates the number of blood feeding instances was reduced to two in the treated fabrics as shown in Figure 2(c). The number of landings were also significantly reduced due to the decreased fabric pore size diminishing the temperature and odor released from the human skin.

**Comfort of Fabrics**

In addition to the thin superfine knit fabrics, a range of other 3-D knit fabrics was produced and trade-offs were established between thickness, air permeability, tactile and thermal comfort parameters (e.g. flexibility, roughness, insulation). Sweating thermal manikin measurements showed no significant decrease in heat loss despite the lower air permeability, leading to similar levels of expected thermal comfort. This allowed an objective assessment of the balance between protection against mosquito bites versus the cost for comfort during wear and engineering of clothing to achieve bite resistance with optimal comfort.

**Acknowledgments**

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**Reference:**


EFFECT OF KNITTING PATTERN ON THE ELECTROMAGNETIC SHIELDING EFFICIENCY OF THE KNITTED FABRICS PRODUCED WITH ELECTRO-CONDUCTIVE YARNS

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Introduction

Application of textile based materials in the electrically conductive products have aroused interest in the last years. Production of conductive yarns are provided by ring spinning, friction spinning, hollow spinning with the combination of metal filament with yarns as well as wrapping staple conductive fibers around the yarn. Improving durability of electro-conductive textile materials in terms of handle, washability and flexibility may be possible by producing electro-conductive yarns with the usage of inherently conductive polymer (ICP) in wet and melt spinning. In addition to these methods, coating fibers with electro-conductive materials such as metal powder, carbon black, carbon nano-tubes (CNT) composite fibers have been developing recently.

Radiation comes from natural and man-made sources. Depending on where you live, the level may increase or decrease in radiation. Radiation can be ionizing or non-ionizing, and radiation is harmful to humans and can cause several (even deadly) diseases. The interest in protecting humans from radiation was created about a century ago. This is because today's society has more and more electrical and wireless devices at their disposal, in addition radio, buildings and industry play a major role in producing different levels of radiation.

The different levels of radiation are reflected in the electromagnetic (EM) spectrum, ranging from ultra-low frequencies (ULF) to extreme high frequency (EHF). In this study, the low frequencies were mainly considered, which are called non-ionizing radiation. These frequencies have only become of interest to investigate when problems were encountered on CTR displays and RF waves. High frequencies can be shielded by a concrete wall or water, but the low frequencies were previously omitted. Because nowadays, more attention is paid to the low frequencies, the question arises, is this harmful to humans? Should human beings be aware and shielded?

There are textiles in the market that shield, for example, clothing for hospitals that protect against X-rays. There are also various conductive yarns made with different production methods. There are also other application methods to apply a coating or film that shields the textile material. A new development is CNTs which are highly conductive and can be used in industrial and medical application methods. There have also been several researches about adding a conductive yarn in a knitted or woven fabric.

Some early studies related to electromagnetic shielding property of fabrics may be summarized; Abdulla et al. examined the electromagnetic shielding characteristics of Milano, Cardigan and Lacoste (pique) knitted fabrics. These fabrics made of hybrid yarns containing 50 μm diameter conductive materials such as copper, silver and stainless steel were produced in order to be
measured for shielding effectiveness measurement. Experimental results show that all factors, especially the geometry of the fabric, have significant effect on shielding property. The best electromagnetic shielding effect (EMSE) values were obtained by Milano type knitted fabrics which was above 20 dB [1]. Lin et al. produced knitted fabrics by using stainless steel (SS)/polyester (PET)/bamboo charcoal (BC) wrapped yarns that have a wrap count of 6.5 turns/cm. The fabrics were evaluated in terms of tensile properties, flexibility, air permeability, far infrared (FIR) emissivity and electromagnetic shielding effectiveness (EMSE). They found that an increase in lamination angle and number of lamination layers positively influenced the shielding effectiveness [2]. Ortlek et al. investigated the shielding effectiveness (SE) of various weft-knitted fabrics made of hybrid yarns considering the structure anisotropy. They determined the shielding property of the knitted fabrics produced on a circular weft knitting machine by using the anechoic chamber with aperture method at different polarizations of electromagnetic waves within the frequency range of 30 MHz and 9.93 GHz. The yarns were selected as siro-spun and siro core-spun without and with a metal core. They concluded that siro core-spun hybrid yarns containing stainless steel are effective for shielding purposes and that SE of knitted fabrics made of hybrid yarns depends not only on the amount of conductive filler but also the orientation of the conductive filler in relation to the direction of the electronic field [3].

Kayacan et al. investigated knitted with conductive copper and stainless steel wires wrapped with acrylic yarns and also core yarns produced by using conductive yarns to test the EMSE properties of the fabrics. They found that the knitted structure of the fabrics affected the electromagnetic shielding effectiveness (EMSE). Besides, the fabrics knitted on a double needle bed of the knitting machine with higher amounts of conductive yarns and unit weights could not provide the targeted improvement in the EMSE values with respect to the fabrics produced on a single needle bed of the knitting machine [4].

There are also some investigations related to evaluation of electromagnetic shielding effectiveness of woven fabrics [5]. Palamutcu et al. introduced a unique design and construction of Electro Magnetic Shielding Efficiency (EMSE) measurement set. Electrical conductive yarns which contain copper wire, silver and cotton staple fibers, were spun and used for production of plain woven as well as single jersey knitted specimens. Produced specimens were tested in the designed EMSE measurement set in the frequency range of cellular phone communication bands. EMSE of the specimens were compared considering yarn components, fabric structure, number of fabric layers, and reference signal power (dBm) based on frequency changes. They found that all these parameters influence the EMSE values. Thin copper wire containing yarn had higher EMSE comparing the specimens produced using thicker copper wire yarns. Double layer of specimen had better EMSE values than the single layer of specimens [5].

Mistik et al. investigated electromagnetic shielding effectiveness, absorbance and reflectance properties of the boron, carbon and boron–carbon plain woven fabrics and boron/polyester, carbon/polyester, and boron–carbon/polyester hybrid composites. A coaxial transmission line holder set-up was used for the determination of the (EMSE), reflectance and absorbance of various fabrics and composites in the frequency range from 15 to 3000 MHz. They found that the carbon fabric and the carbon composite are the most effective structures on the EMSE. Woven fabrics had higher EMSE than the composites [6]. Perumalraj et al. measured electromagnetic shielding effectiveness of copper core yarn knitted fabrics. They observed that an increase in tightness factors, wale density and course density led to an increment in the shielding effectiveness [7].
It was observed that there are limited studies about the evaluation of electromagnetic shielding effectiveness of knitted fabrics produced with the very wide range of knitting patterns including Single jersey, Single pique, double pique, triple pique, interlock, full cardigan, double jersey (full rib), Ottoman and Punto di Roma. In our study, different knitted structures made of twisted yarns with different conductive materials such as copper, silver and steel were investigated. The objective of this investigation is to analyze the influence of yarn type and knitting pattern on the electromagnetic shielding effectiveness of the fabrics.

**Experimental**

In the scope of this study, knitted fabrics with different knitting patterns produced with self-twisted yarns containing conductive yarn were evaluated in terms of electromagnetic shielding properties. An experimental set up was used for measuring the electromagnetic shielding properties of the knitted fabrics. EMSE measurement set has twin antenna (one transmitter and one receiver) used enclosure. Enclosure body is constructed using aluminum-insulation material-aluminum sandwich sheet and signal reflection prevention purposed pyramids. Aluminum box is divided into two rooms with aluminum plate having an empty window of 20cm x 20cm for specimen placement. Whole measurement unit is grounded for electrical purposes. Electromagnetic waves were generated by signal generator, and they were transmitted through the rod antenna to the other room of the enclosure. Signals from the signal generator were measured by the spectrum analyzer with receiver rod antenna placed in the other room. Attenuation of electromagnetic waves from the transmitter antenna to the receiver antenna through specimen surface determined the shielding performance of the related electromagnetic wave frequency.

In total 29 samples have been tested that is including the ‘zero-mark’. Furthermore, a conductive textile with a very fine woven structure with conductive yarn used in the weft and warp direction is being tested.

**Results**

In Figure 1 frequency mark points in a curve diagram the results of all the 29 samples are shown. The red line in the figure shows the ‘zero-mark’, and the blue line is taken from the measured woven fabric with conductive material.

![Figure 3. Frequency mark points in a curve diagram.](image)

In the annex, the experimental setup testing files with all the outcomes of the knitted samples are added in a full document size. This is including a full diagram with the legend and other information. To have a nice overview of the different scores of the fabrics, a bar diagram is made that shows the differences compared with the ‘zero-mark’ which is shown in Figure 2 Tally bar diagram of sample scores in frequency category.
From the shielding results is has emerged that all the samples show a slightly form of shielding. Not every peak is visible, because of the changing waves. There is no clear difference in shielding among the knitted fabrics, also compared with the woven fabric which included a conductive yarn, no clear difference is found. The gathered results shown that some promising findings are harvested. Further studies of the knitted fabrics with special finishing applications may give improved EMSE results.

References:
PREPARATION OF HIGH TEMPERATURE RESISTANT FABRICS WITH HIGH THERMAL SHOCK RESISTANCE

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Introduction
Fire is a destructive burning phenomenon that the flame loses control, and the fire protection suit is a must for protecting firefighter's personal safety. In recent years, many firefighters have died at the scene of the fire. Therefore, the research and development of reload and avoid fire clothing is a hot spot for researchers. The main task of research is to develop an outer insulation material with flame resistance and high temperature endurance. High reflectivity material is used as the reflectance of the outer fabric of the entry clothing, with multilayer insulation structures (MLI) (1), using high emissivity materials as a reflective screen, and the material with low thermal conductivity is used as a spacer. By reflecting the thermal energy of the fire field, it can reduce the heat of the transmission into the fabric and increase the thermal permeability of the entry clothing, while the base cloth can increase the insulation performance of the fabric.

Experimental
Using basalt fiber and glass fiber as the base cloth, the aluminum foil is selected as the outer reflector, and the reflective insulation layer is prepared. Reflective fabric heat insulation coating selection potassium hexatitanate whisker, flame retardant selection of montmorillonite (MMT), including aluminum foil and fabric adhesive alumina high temperature binder. Under the condition of thermal shock and destructive testing of basalt fiber and glass fiber are studied, and the insulation of the heat insulation coating multilayer composite materials, and through the analysis of the single-layer of contrast with heat insulation coating materials, aluminum plating materials and multi-layer plating aluminum composite material, explores the performance of the material.

The research reports the insulating multilayer complex based on basalt fiber, glass fiber and thermal insulation coatings, under thermal shock conditions and destructive testing. Single layer is made of basalt/glass and aluminum foil. Multilayer complex incorporated with thermal insulation coatings were study. Differential Scanning Calorimeter (DSC), UV-Vis-NIR spectroscopy, Thermogravimetric Analysis (TGA), and Air Permeability which is Donghua University Intellectual property was carried out in flashover environment (600-800°C) according to NFPA standards.

Results
The insulation material made in this experiment can last 6-10 minutes in high thermal shock conditions (600-800°C). Apart from slight charring and getting yellow, no brittle damage occurred on the surface of the fabric. All the result indicated that the composite fabric maintained thermal protective performance as well as mechanical properties after fire exposure experiment.

Acknowledgement
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References:
INVESTIGATION OF EFFECTS OF PHASE CHANGING MATERIALS TRANSFER BY COATING METHOD

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Abstract
In this study, it is intended to identify the characteristics of heat regulation in heat-storage microencapsulated fabrics. For this purpose, commercial microcapsules were applied according to the method of impregnation and coating on cotton fabrics. The presence and distribution of microcapsules on the fabric surface was investigated by scanning electron microscopy (SEM). The temperature regulation of the fabrics was examined by means of the temperature measurement sensor and the data recorder system (Thermal camera). Changes in fabric surface temperature due to presence of microcapsules in the fabric structure were determined in the measurements.

1. Introduction
Energy storage plays important roles in conserving available energy and improving its utilization, since many energy sources are intermittent in nature. Short term storage of only a few hours is essential in most applications, however, long term storage of a few months may be required in some applications. Phase change materials (PCM) take advantage of latent heat that can be stored or released from a material over a narrow temperature range. These materials absorb energy during the heating process as phase change takes place and release energy to the environment in the phase change range during a reverse cooling process. Textiles containing phase change materials react immediately with changes in environmental temperatures, and the temperatures in different areas of the body. This system can be used in protective clothing, beds, bedspread etc. [1-6]. In this research, SEM and thermal camera analysis were done and DSC, contact angle and water vapor permeability analysis will be performed.

Materials and Methods
In this research, 100% cotton fabric were used for application of commercial microcapsules with impregnation and coating methods. Commercial microcapsules and other auxiliaries were provided by Devan Chemicals. Polyurethane as a coating polymer were provided by Rudolf Duraner. Morphological features of samples were analyzed by scanning electron microscopy. The temperature regulation of the fabrics was examined by means of the temperature measurement sensor and the data recorder system (Thermal camera).

2. Results and discussion
Scanning electron microscopy (SEM) is used to observe the surfaces of materials with high resolution and magnification. The analysis shows the presence and location of the FDMs transferred by the impregnation method and the coating method.
When the results of the analysis, it is seen that the impregnation method makes the FDM-transferred fabric more effective temperature regulation. Because the impregnated fabric, which has the lowest temperature, absorbs more heat in the cold environment when the PCM structure is applied. However, the results of the analysis show that the coating and the PCM-transferred fabrics do not absorb as much heat as the impregnation method.

3. Conclusion

As a result, it is considered that the coating method may be an alternative to the impregnation method. However, since the analyzes performed do not give information about the performance in the end use areas, performance evaluation according to the usage area will give the most accurate result for the fabrics which are treated by coating and impregnation method.

Acknowledgement

We especially thank to Assoc. Dr. Sennur ALAY AKSOY from Süleyman Demirel University for thermal camera analysis.

Key words: Phase change material, encapsulation, impregnation, coating, thermal camera

References:

HIGH-IMPACT TECHNOLOGY FOR MOTORCYCLE WEAR

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Possible Answer S.A.

Polyanswer® possesses a patented technology based on the production and development of a non-Newtonian fluid from recyclable materials which hardens almost immediately on impact. After the application of the force, the fluid returns to its malleable state. It is possible to incorporate the fluid in different materials, such as polymers (thermoplastic, elastomer and thermosetting), polyurethane system and bi-component filament. Through the use of the fluid, the materials will stand more flexible, lighter and with higher capacity of impact absorption. The technology can be applied in different processing techniques of polymers, mainly in injection and extrusion equipment and machines of textile and footwear industries.

The corporation develops products to areas which require protection: footwear, sports, motorcycle, individual protection and military. Being produced with the fluid, the products ensure to the user the impact absorption, protection, flexibility, ergonomics and comfort. The core purpose is to protect the user from collisions and impacts.

Over the last years, there was a great development in motorcycle protections. With its patented technology, Polyanswer® developed a certified (standard EN1621-1:2012) washable solution which assembles the features of high impact absorption, extreme flexibility, low-profile, ergonomics and comfort. The protections are settled to adapt to temperature variations and guarantee the safety of its users. It is conceivable to position the elements on the inner side of traditional pockets or to thermoform into numerous varieties of textile. A study handled internally favors the design of the parts and certifies a natural movement to the user. Altogether, the features mentioned above generate further adaptable and comfortable gear.

Figure 1. Example of the effect caused on the technology after an impact.

Figure 2. Elbow, knee, hip and shoulder protectors.
Figure 3. Impact tests following the standard EN1621-1.

Key words: non-Newtonian fluid, technology, impact absorption, protections, motorcycle.
DEVELOPMENT OF TEST METHODS FOR CLOTHING PROTECTING AGAINST BITES BY TICKS (IXODIDAE)

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Introduction
In Poland about 20% of ticks are carriers of the Borreliaburgdorferii bacteria, and each year it infects over 3,500 people (1). In 2015, 14,000 Lyme disease cases were registered. Another tick-borne disease is tick-borne encephalitis. In case of this disease it is enough to prick by the infected tick, and there is already a very high risk of infection. There are an average of 250 cases in Poland per year. The number of cases has increased in comparison with previous years. Ticks can be found in different types of habitats. Particularly ticks live in mixed forests, especially adjacent to meadows and pastures and tall grass. They also live in groves, fern areas, low shrubs, lakes and backwaters. In addition ticks can be found often in lawns, parks, backyard and gardens. The ticks attracts white color, warmth, air movement and odor of lactic acid in sweat (2). In the available literature, there are no reports of effective repellent applications in clothing materials, construction of this type of clothing and research methodology for clothing protecting against ticks bites. According to the research conducted at the Institute of Zoomorfolgoy in Dusseldorf (3), the use of repellents in the form of mixtures of permethrin and imidacloprid allows for a significant repellent effect. Taking into account number Lyme disease cases and the effect of this disease to the humans the effective protection of forest workers, farmers and people living in recreational areas is an important problem. According to the European Commission's decision clothing protecting against tick bite, is classified to PPE category II products and therefore the participation of a notified body in the EC type-examination process is required (4). At present, there are no of the notified body for this type of clothing.

Experimental
The aim of the study was to develop test methodology and guidelines for the design of clothing protecting against bites by ticks. Ticks from the species Ixodes ricinus (grazing claws) collected in the wild and multiplied in laboratory conditions were used. These ticks were placed in the laboratory containers in the presence of clothing materials that differ in color, texture, and soaked with repellent solutions. The repellency efficiency of the examined clothing materials were determined, based on the number of ticks that have entered the examined garment and their survival time. Repellents and insecticides of 5 or 6 classes of toxicity (including meta-N, N-diethyltoluamide, imidacloprid and permethrin) were used. The results of these studies allow to determine the properties of the clothing materials (eg type and surface of material, color) and the minimum concentration of released repellents to provide protection against ticks.

Results
Based on the results of the study minimum release concentrations of repellents and/or insecticides are recommended to provide effective protection against ticks. Recommendations concerning the construction of the elements that secrete repellents against ticks will be also formulated. Design of clothing and materials with appropriate texture and color is also to reduce the risk of moving of the ticks under the garment is also discussed. Developed elements are designed to be attached to clothing currently used by forest workers and non-professional garments.
Acknowledgement
This paper has been based on the results of a research task carried out within the scope of the fourth stage of the National Programme “Improvement of safety and working conditions” partly supported in 2017–2019 – within the scope of state services – by the Ministry of Labour and Social Policy. The Central Institute for Labour Protection – National Research Institute is the Programme’s main co-ordinator.

References:
A NEW TEST METHOD TO EVALUATE FLUID LEAKAGE AT THE GLOVE AND PROTECTIVE CLOTHING INTERFACE

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Introduction
Although a large effort has been employed to improve the materials and manufacturing techniques to meet consumers’ design needs, barrier protection, and quality of each personal protective equipment (PPE) element, little attention has been paid to the interfaces and interoperability of PPE (1-3). Of particular concern during the Ebola epidemic in 2014 was the interface between the protective clothing and the glove as blood or body fluids can flow through the protective system worn by healthcare personnel. Even though this area is considered one of the weakest points of the protective apparel system (4), existing standards do not provide sufficient guidance on how to evaluate fluid leakage at the interfaces for healthcare worker PPE.

Experimental
In this study, an innovative test method was developed to determine the fluid leakage at the glove-gown interface. This new test technique utilizes a robotic arm, which has the capability to simulate the arm movements of healthcare personnel when performing various tasks (5). The robotic arm was housed in an experimental chamber where different types of exposures that healthcare personnel encounter are simulated; including spraying, soaking, and physical stresses (e.g., mechanical pressure) (Figure 1). A surgical gown, which claims to meet the “American National Standards Institute/Association for the Advancement of Medical Instrumentation” PB70 Level 4 protection and an extended length examination gloves were used for testing. This study investigated the impact of exposure type, exposure duration, procedure duration, and existence of pressure on the amount of fluid leakage through the glove-gown interface.

Results
Test results highlighted that, with the exception of procedure duration (p = 0.57), all parameters significantly affected the amount of fluid leaked at the glove-gown interface (p < 0.001). Soaking resulted in approximately five times higher fluid leakage compared to spraying. Fluid leakage increased as the exposure duration increased, and was 30% greater with the application of 2 psi pressure. Results suggest that this test method could be used by manufacturers of protective clothing to evaluate their products. Standards development organizations and regulatory agencies could adapt this test method in their standard specifications, testing standards, and guidelines.
Figure 1. The experimental chamber and robotic arm
Photo credit NIOSH NPPTL

References
SURGICAL GOWNS: MEASUREMENTS OF CLOTHING INSULATION WITH A THERMAL MANIKIN

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Introduction
The role of surgical gowns is absolutely essential for the protection of both patient and medical personal involved in surgeries. In the European Union (EU), more than 30 million surgeries are performed every year, fact that should enhance the attention of the society to these medical acts. Surgical gowns based on disposable materials represent an approach but with some disadvantages, namely at the financial and ecological levels. Reusable surgical gowns is an alternative to be considered and a new generation of reusable materials are being developed in order to overcome the past approach and towards a future where a significant reduction of infections within hospital facilities is foreseen. With this goal in mind, a new surgical gown based on reusable materials was developed as a result of a research project coordinated by CITEVE and co-financed by the European Commission. In this paper, the results of the assessment of the thermal insulation of this new surgical gown are presented.

Experimental
Two main devices were used: a climate chamber (CC) and a thermal manikin. The climate chamber has 4.5m×4.5m floor area and variable ceiling height, but a 3 m height was adopted in this work. It has several capabilities to control air temperature, humidity and air velocity in a wide range of conditions. For the present set of measurements the indoor environmental conditions were imposed through control of the inner wall temperatures and the tests took place under calm conditions, with air velocities within the CC lower than 0.15 m.s⁻¹. The thermal manikin used in this study (“Maria”, P. T. Teknik, Denmark), shown in Figure 1, has 16 independent parts controlled by a computer according to a relation between dry heat losses and skin temperature of the human body for conditions close to thermal comfort (1,2). The clothing insulation of a given garment or ensemble can be presented in terms of the total clothing insulation \( I_T \), the effective clothing insulation \( I_{cle} \) for ensembles and \( I_{clu} \) for garments) or the intrinsic or basic clothing insulation \( I_{cl} \) for ensembles and \( I_{cli} \) for garments) (3). On the other hand, different equations can be used to calculate the equivalent thermal resistance of the whole body, namely the serial, the global and the parallel methods. Finally, a manikin can operate with different control modes; typically, equal skin temperatures are considered whenever thermal insulation assessments are foreseen, but a constant heat flux condition and a control mode based on a given equation [namely the thermal comfort equation proposed by (1)] are also used. On this basis, it is important to highlight that, depending on the thermal manikin control method and on the calculation method that is used, the results obtained for the thermal insulation can differ significantly (4,5).

Results
Figure 2 shows the results of the total, the basic and the effective clothing insulations and the thermal insulation of the air layer. In the present analysis the manikin was operating under the
thermal comfort regulation mode, so the results are shown in order to put in evidence the differences between the calculation methods. In fact, with this manikin regulation mode, the values obtained with the “serial”, the “global” and the “parallel” calculation methods are different. Thus, whenever an analysis of the significance of a given thermal insulation value is foreseen, a clear definition of the assumptions on which the result is based has to be stated. For all thermal insulation definitions, the “serial” calculation method present the highest values, followed by the “global” and the “parallel” methods. In the case of the total insulation ($IT$) the results varied between 1.22 and 1.39 clo. The corresponding ranges for the basic and effective thermal insulations were 0.53 – 0.72 clo and 0.42 – 0.57 clo, respectively.

Figure 1. Thermal manikin “Maria” dressed with the surgical gown protective clothing.

Figure 2. Clothing insulations of the surgical gown.

**Keywords:** Surgical gowns; thermal insulation of clothing; thermal manikin

**References:**

A METHOD TO EVALUATE THE BARRIER PERFORMANCE OF PROTECTIVE FABRICS USING VISUAL ‘STRIKETHROUGH’ AS A SURROGATE VIRAL PENETRATION TEST

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Introduction
Hepatitis B and HIV epidemics in the 1980’s increased concern over the transfer of bloodborne pathogens in an occupational setting. Anxiety increased in 1990 when researchers extracted HIV-1 virus from the surface of a fabric that appeared clean (1). The concern over undetected virus penetration prompted two types of standard tests: an inexpensive visual test for ‘strikethrough’ (ASTM F1670 and ISO 16603) and a rigorous viral test for Phi-174 bacteriophage penetration (ASTM F1671 and ISO 16604) (2-5). While these tests were adopted by manufacturers and guidance organizations, the relationship between ‘strikethrough’ and viral penetration was not well understood. A correlation between the volume of fluid penetration and the number of viruses has been demonstrated (6). However, this approach could not present data for concentrations below 10,000 viruses because there was not enough liquid to collect for analysis. The objective of this study is to present an approach to compare visual liquid penetration ‘strikethrough’ to the time of viral penetration.

Experimental
Tests were conducted in penetration test cells with nutrient broth liquid specified by ASTM F1671 (4). One garment type was tested with swatches randomly selected from the same lot. Penetration cells were filled simultaneously from the bottom through a network of flexible polymer tubes. The test protocol was similar to AATCC 127 (7), however, for 5 minutes no pressure was applied, and then hydrostatic pressure increased linearly at a rate of 1 kPa per minute. For liquid penetration tests (n=24), the time of the first ‘strikethrough’ was recorded. For viral penetration tests, rather than wait for ‘strikethrough’ each test (n=57) stopped early at predetermined times. Viral extractions, plating, and pass/fail criteria were conducted according to the ASTM F1671 test method. Binominal (i.e., pass/fail) results of viral tests was determined by logistic regression (ggplot2, R ver. 3.4.2)

Results
For the fabric tested, the average viral penetration preceded ‘strikethrough’ by 37 seconds (Figure 1). With a 1 kPa per minute pressure increase, the 37 seconds corresponded to 0.6 kPa. Using electronic pressure regulation developed for this study, we were able to detect this small pressure difference. Previous studies using an ASTM F1671 apparatus with manual pressure control would not have been sensitive enough to discern a difference between ‘strikethrough’ and viral penetration.
Figure 1. The time of liquid ‘strikethrough’ compared to viral penetration.

Acknowledgement
This study was supported in part by CDC’s National Center for Emerging, Zoonotic, and Infectious Diseases (NCEZID).

Key Words: Strikethrough, liquid penetration, viral penetration, protective clothing

References:
DEVELOPMENT OF A MOTORCYCLE ENSEMBLE: CLOTHING INSULATION APPROACH AND MEASUREMENTS WITH A THERMAL MANIKIN

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Introduction
The protective clothing of motorcyclists can play, particularly in sport activities, a decisive role in avoiding very serious injuries to the users. Moreover, nowadays, the focus of the society on motorsports, as a whole, can be considered as very important but to the fans of these sports everything that surrounds the activity is under their attention. Therefore, in the recent years, the number and importance of industries linked to motorcycling have arisen and achieved a significant social and economic relevance. This study aimed the development of a motorcycle ensemble focused on the research of the most suitable clothing insulation approach. A Portuguese prototype, developed by CITEVE exclusively with materials and technology from Portugal, was compared with two motorcycle ensembles from well-known brands, one from Italy and another from USA.

Development
The clothing insulation approach was composed by a three layer fabric (outer fabric laminated with a breathable waterproof membrane and a knitted fabric) and a insulation detachable complex that can be used as a special lining, specific for cold environments.

Experimental
Two main devices were used: a climate chamber and a thermal manikin. The climate chamber has several capabilities to control air temperature, humidity and air velocity in a wide range of conditions. The thermal manikin (“Maria”, P. T. Teknik, Denmark), shown in Figure 1, has 16 independent parts controlled by a computer according to a relation between dry heat losses and skin temperature of the human body for conditions close to thermal comfort (1,2). The clothing insulation of a given garment or ensemble can be presented in terms of the total clothing insulation (IT), the effective clothing insulation (Icle for ensembles and Iclu for garments) or the intrinsic or basic clothing insulation (Icl for ensembles and Icli for garments) (3). On the other hand, different equations can be used to calculate the equivalent thermal resistance of the whole body, namely the serial, the global and the parallel methods. Finally, a manikin can operate with different control modes; typically, equal skin temperatures are considered whenever thermal insulation assessments are foreseen, but a constant heat flux condition and a control mode based on a given equation [namely the thermal comfort equation proposed by (1)] are also used. On this basis, it is important to highlight that, depending on the thermal manikin control method and on the calculation method that is used, the results obtained for the thermal insulation can differ significantly (4,5).
Results
This paper shows the thermal insulation results of the Portuguese motorcycle protective clothing, which was compared with an Italian and an American reference suits. Besides presenting representative values of these particular protective ensembles made with different clothing insulation approaches, the results are also shown in order to draw attention to the differences between the calculation methods when the manikin operates under the thermal comfort regulation mode (vd. Figure 2). Globally, and as should be expected when the thermal comfort regulation mode is used, the “serial” calculation method present the highest total thermal insulation values, followed by the “global” and the “parallel” methods. Furthermore, the Italian protective clothing shows the highest thermal insulation. The total insulation values (IT) varied between 1,95 and 2,11 clo with the “serial” method. The corresponding ranges for the “global” and “parallel” methods were 1,70 - 1,82 clo and 1,63 -1,74 clo, respectively.

Figure 1. Thermal manikin “Maria” dressed with the Portuguese motorcycle protective ensemble.

Figure 2. Total clothing insulation of the motorcycle ensembles.

References:
SHOE CLIMATE OPTIMIZATION IN WORKING BOOTS

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Introduction
Climatic comfort is an important parameter on shoe comfort, especially for shoes worn for long durations, e.g. working boots (1). Climatic comfort of working boots is influenced by the boot itself, but also by the sock worn as well as by the interaction of foot-sock-shoe. Working boots should not just protect from external threats, but should prevent blisters and runner’s feet by dry foot climate. Climatic comfort is part of long term comfort and a good one leads to lower distraction (1), higher mental and physiological performance (2) as well as to accident prevention during working.

Despite this importance of heat and moisture management of socks and working boots there are just few studies on the interaction of wearer/foot, sock and shoe (3). Many studies focus just on one of the three parameters – foot e.g. Taylor et al. (3), shoe e.g. Schultheis et al. (4), socks e.g. Rossi et al. (5).

Materials and Methods
Five different socks and working boots each were chosen to represent standard constructions. Socks could be divided by fibre chemistry. Working boots have been constructed with different upper materials and linings resulting in different shoe weights.

Thermal insulation $R_c$ and water vapor resistance $R_e$ were measured using a moveable sweating foot model by UCS, Slovenia. It consists of 13 segments which can be heated separately. Sweating was simulated by evenly distributed sweat glands and by peristaltic pumps. Non-covered sweat glands were inactivated.

Measurements consisted of three phases. First hour was in dry state to calculate thermal insulation $R_c$. Second hour was performed with simulated sweating of 24 g/h and was used to calculate water vapor resistance $R_e$. Afterwards drying on the foot was simulated for another 60 minutes after stopping sweating.

Results
Comparing thermal resistance $R_c$ of socks for one boot each, thermal resistance differs just within measurement accuracy (Figure 1). When comparing boots with same sock each, differences between combinations are bigger than measurement accuracy (Figure 1). Highest values of $R_c$ are measured for boot B3 (textile upper, textile liner), lowest $R_c$ for boot B1 (leather upper, leather liner).

Regarding water vapour resistance $R_e$ socks and boots can be differentiated (Figure 1). Comparing socks for one boot each, best/lowest values are measured for S2, highest/worst values are measured for S3 or S4 (Figure 1). Furthermore, ranking of socks is similar when socks are combined with boots. In combination with different socks low water vapor resistance $R_e$ is measured for boots B2, B3 and B4, highest/worst values are measured for boot B1 (Figure 1).

A decrease in heating power after stop of sweating means less water is evaporating due to drying. In regard to this, boot B3 and sock S2 and S5 perform best.
Discussion

In regard to thermal resistance, differences between boots are much bigger than between socks. Even woolen socks S3 and S4 do not provide higher thermal insulation than other socks. It can be concluded that in boots, socks are compressed due to lacing in a way, that insulating air layers in socks become minimal. Furthermore, sample B4 with an artificial fur does not provide higher thermal insulation than further boots. Like with socks insulating air layers are compressed due to lacing.

Moisture management of sock-boot combinations is influenced by socks and boots. Socks containing mixtures of synthetic fibers and cotton (S1, S2, S5) show better results than those containing wool (S3, S4). Wool is absorbing sweat and prevents it from evaporation, resulting in high water vapor resistance and slow drying. With boots lining plays an important role. Leather lining (B1) and artificial fur (WO; B4) show high water absorption, high water vapor resistance and slow drying. On the other hand, boots with PES containing liner (B2, B3) or membrane (B5) show better properties. Best performance is by B3, especially due to fast drying. This is important for working boots, because the will be worn again the next day.

Acknowledgement

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References:
EVALUATING THE ERGONOMICS OF PPE SYSTEMS – HOW MANY SUBJECTS ARE NEEDED?

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Introduction
Standardization on the assessment of ergonomic performance and compatibility of personal protective equipment (PPE) ensembles is one work item of the recently formed group CEN/TC122/WG14 ‘Ergonomics of PPE systems’. Wear trials are still an essential, but cost sensitive approach to evaluate the ergonomics of PPE. The number of required test subjects is of major concern in these costs. Proposed numbers of test subjects vary between three [1] and five [2] for usability testing, and between six [3] and eight [4] for ergonomics evaluation. In order to provide sound recommendations for both writers and users of PPE standards, this paper aims at delineating the statistical principles underlying sample size estimation restricted to the simple, but relevant case of comparing two PPE systems.

Methodological framework
For the work of CEN/TC122/WG14, we define PPE systems as any set of devices or appliances designed to be worn or held by an individual for protection against one or more health and safety hazards. Following [3], we differentiate between comparative testing the performance with respect to mobility, vision, manual dexterity, hearing, thermal issues etc. of two PPE systems against each other on the one hand, and benchmark testing the performance of a system against a benchmark condition, which is often characterized by use of non-restrictive, minimal, light clothing system. To diminish the influence of the inter-individual variability, it is recommended [3, 4] that each test subject should wear each ensemble once in a balanced manner, e.g. following a cross-over design when comparing two PPE systems.

For both comparative and benchmark testing, the user might be interested to show that the means of system A (μₐ) and B (μₐ) are different, i.e. to perform the conventional statistical hypothesis test (SHT1) for differences with null hypothesis Hₐ and alternative hypothesis Hₐ:

H₀: μₐ = μₐ vs. Hₐ: μₐ ≠ μₐ

(SHT1)

Alternatively, non-inferiority testing might be preferable to show that PPE system A does not perform appreciably worse than benchmark B. For this, an ergonomic relevant non-inferiority margin (δ) needs to be specified [5] to substantiate ‘acceptable’ effects, as shown in (SHT2):

H₀: μₐ ≤ μₐ – δ vs. Hₐ: μₐ > μₐ – δ

(SHT2)

We used available procedures for so-called power calculations to estimate the required sample size for both SHT1 [6] and SHT2 [5] types of hypothesis testing using the paired t-Test for the applied within-subject design after specifying standard values for the type-I-error (α=0.05, the probability to erroneously accept H₁ when H₀ is true) and the type-II-error (β=0.2, the probability to erroneously accept H₀ when H₁ is true, i.e. power=1-β=0.8), respectively. Within-subject correlation (r) varied between 0.2 and 0.8 and the mean difference, expressed as effect size ([μₐ-μₐ]/SD) with SD denoting the common or pooled standard deviation, varied between 0 and 4, thus describing trivial to very large effects according to conventions applied in sports.
medicine and exercise physiology [7]. The non-inferiority margin for SHT2 was set to $\delta=0.2$ in SD units indicating the upper limit to a trivial effect [7].

**Results**

Figure 1 shows that the resulting sample size requirements were comparable between SHT1 and SHT2 with slightly lower numbers for non-inferiority testing, but decreased considerably with increasing effect size and also with increasing within-subject correlations.

![Figure 1](image)

Figure 1. Sample size in relation to effect size and within-subject correlation ($r$) estimated for paired t-Tests testing for difference (SHT1, left panel) and non-inferiority (SHT2, right panel) applying standard assumptions for type-I-error ($\alpha=0.05$), type-II-error ($\beta=0.2$, i.e. power=$1-\beta=0.8$) and non-inferiority margin ($\delta=0.2$).

**Discussion**

For sound recommendations on sample size requirements all other relevant details affecting the outcome of the statistical hypotheses test, i.e. design, statistical model and test, significance level (type-I-error $\alpha$), power (1-$\beta$), effect size, and potentially additional information (correlation, carry-over effects,...) must be specified. As a particular requirement to standard writers, expected mean values of ergonomic criteria need to be accompanied by their corresponding sample standard deviations (SD) to enable effect size estimation.

In our case shown in Figure 1, for moderate within-subject correlation ($r=0.4-0.6$), a sample of eight test subjects would have sufficient power to detect moderate to large effect sizes, whereas large to very large effects would be necessary with a lower number of six test subjects. Ergonomic testing with only small expected effect size would require several dozens of subjects, making such tests very expensive and time consuming.

In conclusion, standards on the evaluation of the ergonomics of PPE systems should propose performance tests that are both sensitive and precise in order to limit the required number of test subjects to statistically assess the size of the effect under study.

**Acknowledgement**

The authors gratefully acknowledge the fruitful cooperation with our colleagues within CEN/TC122/WG14.

**Keywords**: PPE systems, ergonomics, standardization, wear trials.

**References**:


THE INFLUENCE OF PASSIVE COOLING DURING RECOVERY ON THE VALIDITY OF PREDICTING FIREFIGHTERS’ CORE BODY TEMPERATURE BY RESTING HEART RATE

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Predictive models of body core temperature have been suggested to prevent severe heat illness for workers exposed to heat stress. In a recent, preliminary predictive model using resting heart rate as a single independent variable was suggested (Kim and Lee, 2015; 2016), yet there are still ongoing issues about the validity of body core temperature prediction by heart rate for those in a real working scene where various environmental factors are combined. This study aimed to investigate the validity of predicting core body temperature using resting heart rate in different types of clothing and environmental temperatures measured in terms of increases and decreases in rectal temperature. The focus was especially on cardiovascular responses caused by passive cooling during recovery because firefighters are encouraged to conduct skin cooling during rest period in the prolonged intermittent work situation.

Six male and five female young participants were recruited for this study. Each person completed three visits on separate days. Maximal oxygen consumption (VO2max) with other anthropometric data was obtained on the first visit. The next visits included experimental protocol with three sessions of cycling for 10 minutes each, and each cycling session was preceded by a rest period of 10 minutes. Cycling load was 50%VO2max, 80%VO2max, and 50%VO2max. When participants wore firefighters’ clothing, climatic chamber was maintained at 25°C and 40%RH, while it was maintained at 40°C and 40%RH for sportswear. Different ambient temperature for different clothing was set in order to reach a similar core temperature at the end of exercise for both conditions. After the last cycling session, participants exited the chamber to where it was room temperature (~21°C). Rectal and skin temperatures and pulse were continuously measured throughout the entire protocol.

The results showed no difference in rectal temperature, whereas there were significant differences in mean skin temperature for the entire experimental protocol, excepting the last cycling phase (p<0.001). On the other hand, heart rate was significantly lower for the sportswear condition during recovery accompanied by skin cooling (p<0.05). This difference caused the relationship between resting heart rate and rectal temperature to be less linear in the sportswear group (r=0.669, p<0.001) than in the firefighter clothing condition (r=0.870, p<0.001). The results showed that skin cooling effect can decrease the accuracy of the predictive model of body core temperature and resting heart rate. On the other hand, for a person without passive cooling, the model performance did not deteriorate. The current study implies that caution is required for the recovery period with skin cooling when predictive model of rectal temperature by resting heart rate is applied to a working site.
Acknowledgement
This research was supported by the Fire Fighting Safety &119 Rescue Technology Research and Development Program (MPSS-Fire Fighting Safety-2015-76; MPSS-Fire Fighting Safety-2015-82).
NON-INVASIVE HEAT STRAIN DETECTION FOR PASSIVE AND ACTIVE HEAT EXPOSURE

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Introduction
Accurate detection of heat strain is important as excessive increases in core body temperature adversely influence physical and mental performance and lead to thermal injuries (e.g., heat stroke; 1,2). Particularly during work on the fire ground, fire fighters are not aware of their thermal status due to high psychophysical stress. Therefore, the prediction of core body temperature and the assessment of thermal strain based on non-invasive measures provides a promising approach for early detection of hazardous thermal stress. This study aims to apply a model to predict non-invasively core body temperature (3) during passive (high clothing insulation in warm environmental conditions) and active heat exposure (moderate physical activity in warm environmental condition), as both exposures can lead to thermal stress. Furthermore, the models performance with regard to prediction accuracy as well as sensitivity and specificity for heat strain assessment will be evaluated. The findings of this study are crucial to better understand the predictive power of the non-invasive model with regard to core body temperature prediction and heat strain assessment.

Experimental
Study participants (n=12) were completing two experimental sessions in a warm and humid environment (air temperature = 35°C, relative humidity = 60%) differing in exercise intensity and insulation of clothing worn. The activity exposure consisted of a cycling exercise at 75% of maximum heart rate performed with sports clothing of low thermal insulation while the passive exposure included a cycling exercise at 50% of maximum heart rate performed with a fire fighter protective garment. Both exposures were preceded by two acclimatization phases, one at room temperature (approx. 20°C, 15min) and the other at experimental condition (35°C, 15min). Participants exercised until volitional exhaustion. The cycling exercise was followed by a recovery phase of 30min duration at room temperature. Non-invasive parameters were measured as described in Niedermann et al. (3) for the non-invasive prediction of core body temperature. In addition, core body temperature was measured directly by a rectal probe 11cm past the anal sphincter.
Results and discussion
Figure 1 depicts an example for the time course of measured and predicted core body temperature. Root mean square deviation (RMSD) was calculated for each participant to assess prediction accuracy (Fig. 2) and sensitivity and specificity values are given for the detection of the 37.5°C threshold as well as the 38.0°C threshold (Fig. 3). The assessment of prediction accuracy based on RMSD provided acceptable results as average deviation was found to be lower than 0.5°C. However, sensitivity and specificity were found to be well below 80% which is not acceptable for heat strain detection. This indicates that the general coefficients for modelling of core body temperature prediction provided and applied by Niedermann et al. (3) need to be further elaborated. There might is a need for the individualisation of the coefficients based on anthropometric or other easy accessible physiological parameters. Furthermore, it can be concluded from the results that the model provided by Niedermann et al. (3) is not affected by the type of exposure. The model seems to predict core body temperature with a similar accuracy for both, active (i.e. metabolic heat gain) and passive (i.e. external heat gain or restricted heat dissipation) heat exposures.

Acknowledgement
We highly acknowledge the support of Shelly Kemp and Rachel Short during execution of human subject trials.

Keywords: core body temperature prediction, heat strain detection, sensitivity, specificity

References:
A WEIGHT THRESHOLDS FOR PHYSIOLOGICAL AND SUBJECTIVE STRAIN ACCORDING TO WEIGHT INCREASE IN FIRE-PROTECTIVE BOOTS BETWEEN 3.2KG TO 5.3KG

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Introduction
Firefighting tasks are one of the most strenuous works requiring ~70%VO\textsubscript{2max} [1] or ~94%HR\textsubscript{max} [2]. A typical firefighting personal protective equipment (PPE) weighs ~30 kg [3]. It is well documented that the heavy and layered PPE increases physiological burden of wearers depending on work intensity, environmental conditions, physical fitness, and/or the load distribution on the body. When carrying a load on the feet, the oxygen uptake per weight was greater than that on the hands and head [4]. However, very few studies on the weight thresholds in protective boots were found. The boots weight differs from countries, foot size, and design (leather or rubber). Further, firefighters do firefighting activities with heavier boots on mud ground or flood floors. In this respect, we aimed to explore a threshold in boots weights to limit physiological and subjective functions while exercising.

Experimental Methods
A total of seven young males participated in this study (24.0 ± 2.9 yr in age, 171.6 ± 4.5 cm in height, 70.9 ± 4.8 kg in body mass, 48.8 ± 3.8 ml·kg\textsuperscript{-1} in maximal oxygen consumption). One preliminary session to get accustomed to all test procedures (2.5 kg in boots), and four experimental conditions were established: 3.2 kg, 3.9 kg, 4.6 kg and 5.3 kg boots (4.5, 5.5, 6.5, and 7.5% of body mass, respectively). Subjects wore identical firefighting turnout jackets/pants, helmets, hoods and self-contained breathing apparatus. A climate chamber was maintained at an air temperature of 28°C with a relative humidity of 50%. Subjects took a 10-min rest on a chair followed by 30-min exercise at a 5.5 km∙h\textsuperscript{-1} on a treadmill and 20-min recovery in the chair.

Results
The results showed that rectal temperature, mean skin temperature, and overall thermal comfort during exercise did not show any difference among the four conditions, while increments in foot temperature (Fig. 1) and heart rate (Fig. 2) were greater for 5.3 kg than other three conditions (P<0.05). Subjects expressed less warm and less uncomfortable over the feet during exercise for the 3.2 kg condition compared to the other three conditions (P<0.05, Fig. 3). These results indicate that the weight threshold on the feet is around 7%BM for physiological strain and around 5%BM for local subjective perception.

Fig. 1. Changes in foot skin temperature
Fig. 2. Changes in heart rate
Fig. 3. Foot thermal comfort
Acknowledgments
This study was supported by the Fire Fighting Safety & 119 Rescue Technology Research and Development Program (MPSS-Fire Fighting Safety-2015-76; MPSS-Fire Fighting Safety-2015-82).

Key words: fire protective boots; physiological strain; weight thresholds; core temperature.

References:
NEW PROTECTIVE CLOTHING TO REDUCE HEAT STRESS AND INCREASE COMFORT FOR OPERATORS IN THE SMELTING INDUSTRY

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Introduction
Workers in the smelting industry are exposed to high levels of radiative heat in their work environment, with a significant risk of being hit by metal sparks or splashes. The leather protective clothing in current use provides good protection against metal sparks and splashes, but brings its own challenges related to heat stress, weight and limited sweat transport and freedom of movement [1,2]. The objective of this project was to develop new protective clothing that reduces heat stress and increases work comfort and performance for workers operating in the tapping area in the smelting industry.

Experimental
The new protective clothing was developed on the basis of a research-based and user-centred innovation process [3]. A user-centred design process develops products based on an in-depth understanding of the user needs and context of use. Insights into user needs, and challenges related to the context of use, were established by group interviews with users, combined with on-the-job observations during visits to two silicon production plants. The insights were translated into design goals, which represented key areas of improvement and the focus for the concept development of the new design. The design goals included reduced heat stress and weight, and improved ventilation and freedom of movement. Prototypes were continuously developed, evaluated and improved through an iterative process of user feedback, resulting in the new protective clothing. The evaluation stage included both testing in a climatic chamber and real-world testing in silicon production plants. A realistic protocol for evaluation of both current and new protective clothing was developed from previous studies on fire-fighters [4,5] and knowledge obtained from field studies at two smelting plants. In addition, a protocol for evaluating cooling (air current 0.6 m · sec⁻¹) during breaks were developed. Ten male subjects (23 yrs., 181 cm, 74 kg) were exposed to a 117 min work and rest schedule (25% and 40% VO₂max) at 25 °C and 35% RH, including eight periods of two minute heat radiation (6000W) in a climatic chamber (Figure 1). Rectal (Tₚₑ) and skin temperatures (Tₚₖᵣₜ), heart-rate (HR), oxygen consumption (VO₂) and subjective evaluation of thermal sensation and comfort were measured.

Results
The weight of the new protective clothing was lowered by 469 grams by replacing leather with modern fabrics in the back panels of the protective clothing. During the field tests, the workers reported improved ventilation, freedom of movement and comfort. The laboratory tests demonstrated that the prototype clothing resulted in significantly lower sweat accumulation, but no significant differences in physiological parameters, due to equal clothing insulation values. Fan cooling during resting periods significantly reduced sweat accumulation and lowered skin temperatures, and had a positive effect on certain subjective sensation and comfort values.

The new protective clothing may help to improve the safety and performance for workers operating in the tapping area in the smelting industry.

Acknowledgement
Industrial partner Industriskinn AS, Norway. The project was co-funded by the Research Council of Norway (2015.245616/O30).

Keywords: Molten metal, protective clothing, heat stress, physiology, user-centred design.

References:
WORKWEAR FOR MULTI PROTECTION OF PERSONNEL ON SEA OBJECTS OF THE ARCTIC OFFSHORE

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Introduction
Work on sea production platforms of the Arctic offshore is one of the heaviest and dangerous because it is performed in extreme climatic and working conditions different from the Continent: sharp change of weather, high humidity of the air which saturated with sea salt, low visibility in view of frequent fogs and polar night, frequent and strong winds, extremely low air temperature. Climatic conditions of the Russian Arctic offshore are more severe in comparison with projects of Norway (including in the Barents Sea), Great Britain and Canada. We have developed a new class of workwear that provides multi protection of personnel of offshore facilities in the extreme conditions of the Arctic. Protective clothing was developed taking into account the actual working conditions of the Arctic offshore and the wishes of the personnel of offshore facilities. Before it became final, the test industrial operation of the products was conducted during 2014-2015 on semi-submersible drilling platforms "Polar Star" and "Northern Lights" in the water area of the Sea of Okhotsk and 2016-2017 on the only Arctic sea ice-resistant fixed platform Prirazlomnaya. The whole collection consists of 16 items and includes winter suits and overalls, summer suits and overalls, suits and overalls for work in a residential block. During the manufacture of products are used hi-tech textile materials of new generation which have been specially developed for this project: fabrics with a membrane, steady against sea salt, the super lightweight material warming nonwoven fabric and lining fabric with 3-D structure.

Experimental
According to the laboratory researches, the best protective and stable characteristics in the operation on the offshore are fabrics made from a mix of fire-resistant chemical, natural and synthetic fibers, compared to a group of fabrics only from natural (100% cotton) or only from chemical (meta-aramide 100%) fibers. Fabrics made from a mix of meta-aramid (30%), cotton (25%), modacrylic (30%) and polyamide (10%) fibers have the highest resistance to abrasion - more than 75 thousand cycles and the highest hygroscopicity - more than 25%. In addition, our studies of the effect of sea salt on the properties of textile materials have shown that sea salt has the greatest destructive effect on cotton fabrics. This group of fabrics substantially loses strength characteristics as a result of "getting" of crystals of sea salt in structure of materials and destruction of fibers and loses a color - as a result of destruction of the painting pigment and antistatic properties - as a result of destruction of molecular communications (Figure 1).

Figure 1. Photos in the structure of textile material impregnated with sea salt crystals.
The new nonwoven fire-resistant fabric Melamine from ultrathin fibers has been developed for production of winter suits. According to laboratory researches, the total thermal resistance of Melamine is 1.5 times higher than today’s available fire-resistant non-woven materials with the same surface density. With this ability, we used only one layer of non-woven fabric Melamine instead of three, which are now used for warm clothes. The additional advantage of Melamine is a high resistance to open flame. It is characterized by keeping the exposed flame for more than 2 minutes. Additional physiological comfort in the use of products is provided by the innovative lining fabric and the presence of a "third dimension" in it, which has high thermal insulation due to the 3-D structure, high air permeability, permanent hydrophilic effect, improved flexibility. To maintain the optimal human thermal balance under variable temperature conditions, for example, changing the weather conditions, we developed a special 3-layer concept (3 Layer System ™) recommended for use in special clothes for difficult conditions in the ISO DIS 35101:2016. Due to the presence of separate layers by which the cold-protective properties of clothing can be varied, a set of cold protective clothing can be used in a wide range of temperatures from +15 °C to -50 °C.

Results
Today all the staff of the Prirazlomnaya wears these protective clothing (http://shelf.gazprom-neft.ru). We conduct constant monitoring and interview staff every 3 months. The workers note the high ergonomics of the products, the convenience of weighing 4 kg, the total weighs 3 kg, the special clothes are not blown by the wind, well "breathes" and quickly removes the excess of the material from the human body. Tests of special clothes in the climatic camera in research laboratory of Central Research and Development Institute of clothing industry have been in addition carried out. The developed special clothes provide thermal comfort at a temperature to –50 °C within 2 hours. The general thermal insulation can be changed depending on weather conditions due to existence of different layers of a set. The workwear reliably protect from thermal risks according to requirements of ISO 11612, have the third index of protection against an atmospheric precipitation according to requirements of DIN EN 343 and provide protection against accumulation of static electricity according to EN 1149-5. Due to use of the new special clothes providing multiprotection in severe conditions of the Arctic offshore health of workers remains, their operability and level of individual safety on dangerous sea industrial facilities improves.

Keywords: Cold Protective Clothing, PPE, Arctic Offshore.

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FUNCTIONALITY OF WORK WEAR CLOTHING BASED ON DIMENSIONING SILHOUETTES AND USERS PREFERENCES

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Abstract

The correct selection of work clothing should be supported by the knowledge of working conditions, taking into account the existing threats and the nature of the activities performed. Knowledge of the intended use of workwear for specific working conditions and the basics of programming constructional, technological and material features of clothing are important elements of the activities of the creators of new clothing solutions. In ergonomic design, human anthropometric data must be taken into account to maintain proper proportions between body dimensions and optimal dimensions of the work area. In order to achieve optimal functionality and comfort of using work clothes while designing workwear, the preferences of end users should also be taken into account.

The article presents the process of improving the comfort of using work clothing and its functionality based on dimensioning of work users' profiles using the latest human body 3D scanning technologies, surveys of their preferences and analysis of the producer's clothing size table. There were selected one model of work wear clothing, produced by Krystian company. Then the end users – employees of the construction company were chosen. The working group has been subjected to non-contact measurement using a 3D body scanner as well as questionnaire surveys. Information was obtained the size of work clothing and preferences regarding construction and functionality changes. The obtained data was analysed along with measurement data of the scanned builders. The conformity of the work clothing dimensions to the manufacturer's size table was examined.

An analysis of the questionnaires regarding the comfort of using the clothing gave a chance to increase the comfort of work, and the results obtained from the measurement data, allowed the introduction of structural changes in both the sweatshirt and in the dungarees of work clothes. On the basis of obtained results of measurement, benchmarking and preferential, designed construction and technological solutions were illustrated in the clothing parts, increasing the comfort of use and the functionality of workwear, by fitting clothing to build the users' profiles, including the range of movements resulting from the specificity of the work, like changing the size of the mobile phone pocket due to their larger size this days or construction changes of a bib in dungarees. Structurally modified products were tested by end users for fitting.

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Keywords: Functional clothing, user comfort, clothing fitting, body size, 3D body scanner.
COMPARISON OF THE EFFECT OF THERMAL AGING ON 
THE MECHANICAL PERFORMANCE OF FIRE 
PROTECTIVE FABRICS

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Introduction
High performance fibers have been developed over the last fifty years to manufacture fire protective clothing for firefighters and others at risk of heat and flame exposure [1]. However, the various conditions the materials are exposed to during the lifetime of the clothing reduce their performance over time. A series of testing campaigns carried out on used firefighter turnout gear revealed significant losses in mechanical and barrier performance [2]. For instance, 11% of the outer shell samples tested in the 2-4 year old category failed to meet the tear strength requirement. That percentage increased to 22% in the 5-10 year old category and to 75% for turnout gears older than 10 years. In addition, large losses in the breaking force of a Kevlar®/PBI blend fabric used as outershell in firefighters’ bunker suit were recorded as a result of thermal aging at 190°C, which is the continuous operating temperature reported for Kevlar in the literature (PBI has a tabulated thermal index of 250°C) [3]. Research is thus needed to better understand the aging behavior of the different fabrics used in fire protective clothing and allow end-users to select the best material for their work conditions.

Experimental
Seven woven fabrics typically used in fire protective clothing were selected for the study: #1: 100% Kevlar®; #2: 93% Nomex®/5% Kevlar®/1% carbon (Nomex® IIIA); #3: 60% Kevlar®/40% Nomex® IIIA; #4: 60% Kevlar®/20% Nomex®/20% PBO; #5: 60% Kevlar®/40% Basofil®; #6: 100% Nomex®, and #7: 60% para-aramid/40% PBI. Specimens were subjected to accelerated thermal aging using an electrical convection oven for times ranging between 1 and 500 hours at 5 different temperatures: 150, 190, 210, 235, and 300°C. The effect of accelerated thermal aging on the fabrics was assessed in terms of tear strength using trapezoidal tear specimens. The temperature contribution to the thermal aging process, i.e. the activation energy (Ea), was determined by applying the time-temperature superposition (TTS) principle to the residual tear strength data and displaying the shift factors on an Arrhenius plot. The degradation time rate (n), midpoint time (K), and ultimate tear force (σu) were obtained by fitting the TTS master curve with the 3-parameter Hill equation.

Results
Figure 1.a shows the residual tear strength data recorded for fabric #5 at different aging times and temperatures. The loss in tear strength reached 45% after 150 hours of aging at 190°C, even though that temperature corresponds to the thermal index of 190°C reported for Kevlar® and is below that of Basofil® (200°C) [4]. The master curve at a temperature of 150°C obtained by applying the TTS principle to the residual tear strength data is shown in Figure 1.b. The associated shift factors displayed in an Arrhenius plot (insert in Figure 1.b) show a good agreement with the Arrhenius model. Figure 1.b also shows the result of the fit of the TTS master curve data with the 3-parameter Hill equation. The Hill equation fit curves for all seven fabrics are displayed in Figure 2 and the values of the four parameters characterizing the aging
process as well as the initial tearing force ($\sigma_i$) are provided in Table 1. These results can be used as a guide to select fire protective clothing based on the type of work conditions.

![Figure 1. Effect of thermal aging on fabric #5.](image)

![Figure 2. Hill equation fit curves for the fabrics tested.](image)

**Table 1. Parameters characterizing the aging process.**

<table>
<thead>
<tr>
<th>Fabric</th>
<th>$\sigma_i$ (N)</th>
<th>$E_a$ (kJ/mol)</th>
<th>$K$ (h)</th>
<th>$n$ (h$^{-1}$)</th>
<th>$\sigma_u$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1</td>
<td>387</td>
<td>95</td>
<td>124</td>
<td>0.62</td>
<td>0</td>
</tr>
<tr>
<td># 2</td>
<td>131</td>
<td>90</td>
<td>8422</td>
<td>0.41</td>
<td>0</td>
</tr>
<tr>
<td># 3</td>
<td>125</td>
<td>113</td>
<td>1050</td>
<td>0.64</td>
<td>23</td>
</tr>
<tr>
<td># 4</td>
<td>342</td>
<td>103</td>
<td>550</td>
<td>0.51</td>
<td>7</td>
</tr>
<tr>
<td># 5</td>
<td>140</td>
<td>105</td>
<td>3092</td>
<td>0.88</td>
<td>12</td>
</tr>
<tr>
<td># 6</td>
<td>122</td>
<td>81</td>
<td>1895</td>
<td>0.65</td>
<td>28</td>
</tr>
<tr>
<td># 7</td>
<td>227</td>
<td>111</td>
<td>688</td>
<td>0.95</td>
<td>39</td>
</tr>
</tbody>
</table>

**Acknowledgements**

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**Key Words:** Fire protective fabrics; Thermal aging; Tear strength retention; Time-temperature superposition principle; Arrhenius plot; Hill equation.

**References:**


COMPARISON OF PHYSICAL AND BARRIER PERFORMANCE OF REUSABLE ISOLATION GOWNS

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Introduction
Gowns are the second-most-used piece of personal protective equipment (PPE), following gloves, in healthcare settings (1). Isolation gowns are a type of protective clothing used by healthcare workers to protect themselves and patients from the transfer of microorganisms and body fluids in patient isolation situations. Recent infectious disease outbreaks highlighted the need for more effective PPE, including isolation gowns. Isolation gowns are generally classified as “disposable/single-use” or “reusable/multi-use”. In the United States, disposable isolation gowns are used more commonly, while in Europe the share of reusable gowns is larger. Reusable isolation gowns are typically made of 100% cotton, 100% polyester, or a polyester/cotton blend and laundered after each use. In general, reusable garments can be used for 50 or more laundering and drying cycles. The manufacturer provides the suggested number of laundering and drying (processing) cycles (2). Physical and barrier performance of isolation gowns are critical to provide appropriate protection to the healthcare workers. However, there is limited information about how physical and barrier performance of reusable isolation gowns are affected by multiple processing cycles. This study assesses performance changes of nine reusable isolation gowns after the first and multiple processing cycles.

Experimental
Five Association of the Advancement of Medical Instrumentation (AAMI) PB70 (3) Level 1 and four AAMI PB70 Level 2 isolation gown models were laundered and dried one time as recommended by the manufacturers. Physical performance properties were assessed using tensile strength, tear resistance, and seam strength test methods. Barrier performance of the gowns were tested using two standardized water resistance test methods for each of the three critical areas defined by AAMI PB70, namely, sleeve seams, chest, and point of attachments. These nine gown models were also laundered and dried to the maximum laundering cycles (72-100) suggested by each manufacturer and physical and barrier performance were assessed after multiple processing cycles. Test results were compared between AAMI PB70 levels and after one and multiple laundering and drying cycles.

Results
Tenacity, tear strength and seam strength of isolation gowns significantly decreased with multiple processing cycles (p<0.001). Also, barrier resistance properties of AAMI Level 1 gowns did not change significantly after multiple processing cycles while barrier resistance of AAMI Level 2 gowns slightly improved only for the chest region. There were no significant changes to barrier resistance of other regions. This study fills a gap in the area of performance change of reusable isolation gowns after multiple processing cycles and provides the physical and barrier performance data for reusable isolation gowns using standardized laboratory test methods. Physical performance of reusable...
isolations gowns was significantly impacted by multiple processing cycles while barrier resistance properties remained unchanged in general.

Figure 1. Effect of Multiple Processing Cycles on Tenacity of Fabrics

References
Introduction
Firefighter’s PPE is to ensure the safety of firefighters during their activities [1]. However, if the performance of the PPE is too high, the firefighters may not only feel their working environment but misunderstand their performance and finally lead to a serious accident. For that reason, today's PPE for firefighters is expected to have sensor equipment to alert him/herself and the surrounding team for the danger [2] [3]. High-tech sensing clothing, so called “wearable clothing”, has been developed, but the issue would be costly expensive and how to maintain its performance over the years with use and washing. Therefore, costly inexpensiveness and easy maintenance device must be developed. This research is fundamental to develop how to monitor the environment outside and inside of firefighter’s gear and the experimental result at field test.

Experimental
Firefighter’s gear has 34 sensors. Figure 1 shows the description of the sensors and its location. Our objective of field test is to see (1) the system properly works to understand test condition in fire room, (2) the environment at surface and inside of firefighter’s gear (ex. incident heat, (3) heat transfer through the multi-layers fabric and (4) humidity condition under the clothing). Figure 2 shows a picture of the experimented room. Fire source is 5 liters of kerosene in a steel pan of 800 mm × 800 mm × 200 mm. Once fuel was ignited, 1 L of kerosene had been added every one minute during the experiment. Sensors for the room temperature measurement were nine sheathed thermocouples (ø 1.0, K-type) at constant intervals from floor to ceiling (3 m height) and temperature and humidity sensors (Sensirion SHT31) at 400 mm and 800 mm. The position of the firefighter, who wears our developed gear with sensors, was 1400 mm away from center of the fire and 600 mm away from the sensors for measuring the environment in the room. He repeatedly changed his knee’s posture every 30 seconds for 15 minutes (Figure 3), which left and right knees ware on floor and then only left knee was on the floor.

Results
- Test environment
Fire room had temperature distribution as layers according to their heights (Figure 4). And two temperature zones were distinguished at 1,200 mm. Since fuel is not continuously supplied like gas fuel, kerosene fuel had been repeatedly added. Therefore, temperature difference in a fire room before and after fuel added was 130 °C in upper zone and 65 °C at 800 mm from the floor in lower zone, which the height of firefighter’s chest. Average upper zone temperature was ranging from 200 to 300 °C and lower zone was from 40 to 150 °C. Relative humidity which firefighter’s position was 15 % at 400 mm height and 6.3 % at 800 mm height on average.
- Firefighter gear
For helmet, the highest temperature was at forehead and 154 °C at maximum at 880 seconds. This is because the firefighter was facing to the fire. At forehead, innermost temperature was from 2.1 % to 32 % higher than innermost at the top of the head. Average temperature at each layer on right chest during experiment was 89 °C, 67 °C and 3 °C, respectively (Figure 5).

Average temperature of left and right knee was 34 °C and 71 °C, respectively, but the right knee reached over 100 °C three times. This is because the knee faced on fire source when the posture of right knee was changed. The relative humidity between the thermal liner and under clothing always kept between 80 and 90% R.H. after the firefighter wore the clothing. As a result of the field test, our developed firefighter’s gear with wireless sensing showed that it makes possible to monitor the environment outside and inside of firefighter’s gear.

Acknowledgement
This work was supported by JSPS KAKENHI Grant Number JP15H01789 and JP16H03133.
Keywords: PPE; wireless sensing; temperature measurement; relative humidity; heat flux; thermal environment; firefighter; field test.

References:
As of April 2018 the new PPE regulation 2016/425 is applicable. During one year of transition time PPE distributors are still allowed to place their products on the market as long as licensed under the obsolete Directive 89/686/EEC. Certifications to the obsolete Directive are still valid until 21 April 2023 [1]. In spite of these transition periods PPE distributors are facing a considerable effort to get their product portfolio ready for the new directive. According to the new directive the PPE distributors are obliged to provide evidence on “conformity to type based on quality assurance of the production process” to obtain a certification. This very quality assurance of the production process requires a thorough surveillance and reporting of every process step.

On one hand effort necessary to implement the new directive is an enormous burden for the PPE distributors, on the other hand it can be seen as a chance to implement a novel upgraded quality assurance of the manufacturing process by using concepts of Industry 4.0. In present work an approach is introduced that supports participants all over the complete manufacturing process route of PPE products by giving an example of a textile-based interconnected manufacturing process. As a wide range of PPE available in the market is based on textile components the presented results are suggested to be highly relevant for the PPE industry.

As the PPE distributors most often use raw materials supplied by third parties (suppliers) they have to strongly trust in their suppliers’ protocols and provided data sheets. As singular failures in the suppliers’ production process may have no effect on the correctness of the provided data sheets, resulting failures in the manufacturers’ production process and hence a reduction of safety of the resulting product may nevertheless occur.

One example may be a manufacturer of fall protection equipment who processes narrow woven fabrics to obtain his belt systems. The manufacturer is supplied by a weaving mill that provides correct data sheets, but who has had a problem in the initial phase of yarn preparation, e.g. an insufficient warp yarn tension. The insufficient yarn tension is a value not provided by the data sheet, but which has a significant effect on the elongation behavior when stress is applied (e.g. in a fall test according to DIN EN 355 [2]). Due to the reduced warp tension in the manufacturing process of the woven fabric the elongation of the belt is defective in a way that the energy absorption occurs in a sudden moment instead of successive controlled energy absorption. This leads to a sudden tension build-up and causes significantly increased mechanical load to be borne by the user. The product would accordingly fail the certification process and a costly investigation of failure origin and liability would be the consequence. If now a sensor-system would allow a continuous surveillance of the warp yarn tension throughout the warping and weaving process and a data processing system would be established that logs the obtained data, the weaving mill could provide evidence of a stable manufacturing process. In case of irregularities the weaving mill could provide the information to the PPE manufacturer that a production lot may lead to complications in the further processing and testing. The knowledge on the quality and stability of sections of manufacturing process steps can under specific conditions lead to avoiding failure in later process steps. This interconnection...
of manufacturing processes has accordingly a high potential to save costs and to increase safety of PPE.

In the project “Smart Factory” within the project framework of futureTEX a consortium of research institutions and SMEs has worked out approaches to support textile companies in establishing interconnected process chains (as shown in Figure 1) [3]. As a result the Smart Factory approach determines the machine communication strategy based on the real time process and product quality assessment. By upgrading the physical machines to cyber-physical systems the quality relevant process data can be acquired from each process. This data is used to optimize the production quality in the entire production chain. The determined machine communication strategy gives a plan which kind of process data is to be obtained from and transferred to which production process. The presented work shall be a basis to discuss how an automatic quality control could provide a way to improve the efficiency of currently used systems for the quality assurance of the manufacturing process. The project results could hence lead to supporting the manufacturers in implementing the new directive at the same time increasing safety of their products and decreasing costs due to failure investigation.

Acknowledgement
The project “Smart Factory” is part of the project framework “futureTEX” which is funded by the German Federal Ministry of Education and Research within the programme “zwanzig20 – Partnerschaft für Innovation (twenty20 – Partnership for innovation)”.  

Keywords: quality, process, automatic, smart factory.

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Ableitung von typischen Industrie 4.0; Wissenschaftliche Schriftenreihe des Institutes für Betriebswissenschaften und Fabriksysteme; ISSN 0947 – 2495; 2017; Chemnitz
EVALUATION OF DIFFERENT AMBIENT AND CLOTHING CONDITIONS FOR THRESHOLD LIMIT VALUE OF OCCUPATIONAL HEAT STRESS: PILOT STUDY

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National Institute for Occupational Safety and Health, National Personal Protective Technology Laboratory

Introduction
One of the commonly used administrative decision tools to determine the allocation of work-rest schedules for the prevention of occupational heat stress is American Conference of Governmental Industrial Hygienist’s (ACGIH) Threshold Limit Value (TLV) (1). The TLV is determined based on three factors: ambient air condition expressed in Wet Bulb Globe Temperature (WBGT), work intensity, and clothing adjustment factor. The main purpose of the TLV is to allow workers to maintain a heat balance, and therefore prevent core body temperature (Tc) elevation within +1°C (e.g. ≤ 38 °C). One of the underlying assumptions for this practice is that a level of heat stress would be equivalent to different combinations of ambient temperature and relative humidity should it be matched to the equivalent in terms of WBGT. Therefore, the purpose of this study was to evaluate heat stress of workers exposed to different combinations of ambient and clothing conditions by following the ACGIH TLV.

Procedure
Eight healthy, non-smoking men (age: 22.6±1 years, height: 178.9±8 cm, weight: 77.7±14.6 kg), recruited for a preliminary data collection, wore either work clothes (WC) (one-piece long-sleeve cotton coverall, hardhat, and gloves: assigned clothing adjustment factor [CAF] of 0°C WBGT) or chemical protective clothing (CPC) (powered air-purifying respirator, chemical resistant coverall, and gloves: assigned CAF of 11°C WBGT). Subjects underwent four cycles of an intermittent work-rest (15min each, total 2 hours) under two levels of ambient conditions characterized as either dry (DRY) or humid (HUM), but equivalent to 30°C WBGT. They performed a cycling exercise at a fixed rate of 350W in metabolic heat production while sitting on a chair and removing gloves and headgear with hydration ad lib during the rest period. Due to the difference in clothing adjustment factors between WC and CPC, DRY and HUM were set as 45.5°C, 15% and 31°C, 84% for WC and 30°C, 15% and 20°C, 80% for CPC. Tc elevation (measured by rectal temperature), physiological strain index (PSI) and perceptual strain index (PeSI) were measured and analyzed for the interaction between ambient and clothing conditions.

Results
Final Tc, PSI, and PeSI at the end of the fourth work cycle in each condition are presented in Table 1. There was no significant difference in the final Tc (p=0.151) or the magnitude of Tc elevation between conditions. There was also no significant difference for PSI (0.101) while a significant interaction was found for PeSI (p=0.015) showing that PC-HUM exhibited a lesser PeSI than other conditions.

Discussion
The final Tc was maintained below 38 °C and the magnitude of Tc elevation was not greater than 1 °C in all conditions although Tc endpoint was variably affected by different clothing and WBGT combinations. However, it is important to emphasize that the current exposure duration was only 2 hours and Tc elevated continuously during the cycles of work and rest. This implies...
that the current TLV practice does not offer a complete heat balance as previously identified (2) and would be unlikely to protect workers from heat stress, especially in an extended period of heat exposure. An estimated mean Tc elevation for a typical 4 hour-half day work schedule when wearing WC or CPC in 30 °C WBGT is 1.49 and 1.35 ºC, respectively, equating above 38°C. Further, the CAF for CPC may need further heat balance analysis as the present results show a Tc difference of about 0.2º C and lowest PeSI in PC-HUM where low ambient temperature and high humidity combinations were implemented. More data collection is underway and findings from this study are expected to provide information to better analyze ACGIH’s TLV practice, as well as to help refine the current guidelines to prevent occupational heat stress.

Table 1. Summary of Tc, PSI, and PeSI at the end of the fourth work cycle

<table>
<thead>
<tr>
<th>Variable</th>
<th>WC-DRY</th>
<th>WC-HUM</th>
<th>PC-DRY</th>
<th>PC-HUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc (ºC)</td>
<td>37.74±0.32</td>
<td>37.67±0.43</td>
<td>37.65±0.35</td>
<td>37.46±0.37</td>
</tr>
<tr>
<td>Δ Tc (ºC)</td>
<td>0.77±0.38</td>
<td>0.72±0.24</td>
<td>0.74±0.39</td>
<td>0.62±0.27</td>
</tr>
<tr>
<td>PSI</td>
<td>3.7±0.9</td>
<td>3.1±0.5</td>
<td>3.5±1.0</td>
<td>2.6±0.8</td>
</tr>
<tr>
<td>PeSI</td>
<td>4.1±0.9</td>
<td>3.6±0.8</td>
<td>3.9±0.9</td>
<td>2.7±1.1</td>
</tr>
</tbody>
</table>

Acknowledgement
This study was funded by the Office of Public Health Preparedness and Response. Disclaimer: The findings and conclusions of this abstract are those of the authors and do not necessarily reflect the views of the National Institute for Occupational Safety and Health.

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USE OF A HUMAN BODY THERMOREGULATION MODEL TO EVALUATE FIRE PROTECTION CLOTHING

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Introduction

The high level of physical work required during firefighting leads to high rates of metabolic heat production. Additionally, the heat fluxes gained by the body due to the impinging of thermal radiation from flames, the exchange of infrared radiation with the surroundings, the convection with surrounding hot gas (air and smoke), the conduction from heated grounds and solar radiation also have to be considered. If, as result of this combination of heat gains, the hypothalamus temperature exceeds certain values, important and undesirable incidents can occur with a firefighter (1), namely introversion (violent sweating, misleading, amnesia, etc.), superficial skin damages (pain and burn degree 1), heat stroke (fainting, stop of sweating, central nervous system alteration, etc.) and permanent injuries (burn degree greater than 1, brain damage or, in the more serious cases, death).

Wearing high thermal insulating protective clothing reduces the gain of external heat, but also blocks the release of the heat produced and restricts movements. Then, in order to improve safety during firefighting, the wearing of clothing with very special requirements is required, namely thermal properties appropriated to the fire intensity. Unfortunately, it is difficult to find studies reporting the relation between the fire intensity and the recommended thermal properties of the protective ensemble. In fact, such field studies can lead to high core temperatures. This drawback can be overcome by using validated models for the simulation of the human body thermophysiological response when exposed to very hot environments, with high levels of impinging thermal radiation.

Human body thermoregulation modeling

The performance of firefighter protective clothing is assessed using the HuTheReg software (2), which predicts the thermophysiological response of the human body when exposed to a wide range of conditions, namely different types of thermal environments (severe cold, cold, cool, neutral, warm, hot and very hot) with (or without) impinging thermal radiation, different exposures (uniform, sudden change and cyclical), different exercise intensities and different types of clothing. This program predicts a significant variety of data, both for the human body as a whole and for body regions, namely: (i) core, muscle, fat, skin and clothing temperatures; (ii) metabolism, heat stored and flux-rates of heat, of sweat, of water and of work; (iii) thermal comfort evaluation and indexes; (iv) detection of probable appearing of heat-related disorders within the person; and (v) skin pain, burn areas and corresponding degree.

Results

For present purposes, a firefighter exposed to a high intensity fire was considered. An incident radiation heat flux of 10 kW/m² was chosen, above the 7 kW/m² flux indicated in the literature.
(3) as capable of producing second degree skin burns in 90 seconds on firefighters wearing Nomex ensembles with 210 g/m2.

Based on the prediction of the thermophysiological response of the human body, the maximum exposure times to avoid the risk of important undesired incidents were identified and related with the firefighter personal protective clothing properties. Figure 1 shows the time delay to the onset of these heat-related illnesses (a) and the evolution of rectal, hypothalamus and maximum skin temperatures with time for three different levels of clothing insulation, representing three levels of global thermal protection: weak (b), current (c) and strong (d).

The analysis of the results indicates that the enhancement of firefighter safety can be achieved through the increase of both clothing insulation and vapour permeability efficiency and by the decrease of the emissivity of its external surface. However, besides this, the safety of firefighters is essentially related with a good control of the exposure period to the high intensity radiation fluxes. The increase of safety firefighting periods requires the wearing of improved protective clothing, for instance through the incorporation of elements for dissipation of thermal energy (with ice blocks, impregnated with water, …), of components capable to reflect the incoming thermal radiation (radiation shields, …), etc.

(a) Relation between clothing insulation and time for the beginning of heat related illness.

(b) Protective ensemble with 1.21 clo (weak).

(c) Protective ensemble with 2.45 clo (current).

(d) Protective ensemble with 4.73 clo (strong).
References:
COMPARISON OF THERMAL MANIKIN MODELING AND HUMAN SUBJECTS’ RESPONSES DURING USE OF COOLING DEVICES UNDER PERSONAL PROTECTIVE ENSEMBLES IN THE HEAT

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The purpose of this study was to examine the physiological impact and heat perception of four different personal cooling devices (PCDs) under impermeable personal protective equipment (PPE) during low-intensity exercise in a hot/humid environment using thermal manikin modeling and human testing.

Six healthy male subjects walked on a treadmill in a hot/humid environment (32°C/92% relative humidity) at 3METs for 60 minutes wearing PPE recommended for use in West Africa and one of four different PCDs (PCD1, PCD2, PCD3, PCD4) or no PCD (CON). The same ensembles were tested with a Newton Sweating Thermal Manikin (Thermetrics; Seattle, Washington USA) in the same conditions to compare the results. The manikin is controlled via ThermDac software running a RadTherm finite difference thermal analysis program (ThermoAnalytics, Inc.; Calumet Township, Michigan USA) to perform a Fiala thermoregulation model.

All PCDs seemed to reduce physiological heat stress characteristics when wore under PPE compared to CON. Both the manikin and human testing provided similar results in core temperature (Tc) and heat sensation (HS) in both magnitude and relationship. While the manikin and human data provided similar skin temperature (Tsk) characterization, Tsk estimation by the manikin seems to be slightly over estimated. Weight loss, as estimated by the manikin, was under-estimated compared to the human measurement.

PCD use in conjunction with impermeable PPE may be advantageous in mitigating physiological and perceptual burdens of heat stress. Evaluation of PCDs worn under PPE can be done effectively via human or manikin testing, however, Tsk may be over-estimated and weight loss may be under-estimated. Thermal manikin testing of PCDs may provide fast and accurate information to persons recommending or using PCDs with PPE.
EFFECT OF MOISTURE IN UNDERGARMENTS ON PROTECTIVE PARAMETERS OF CLOTHING SET PROTECTING AGAINST HEAT AND FLAME

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Introduction
Protective clothing for workers exposed to thermal factors should comply with the requirements of the EN ISO 11612:2015 standard and should protect them in case of short-term contact with fire and against the effects of convection heat, radiant heat, contact heat. The presented requirements are applicable only to outer garments, most exposed to hazards.

The conducted research confirms that, in addition to the outer protective clothing, also the garments worn underneath have an impact on providing adequate protection for the employee, as well as a major impact on thermal comfort of the clothing user. Therefore, the right choice not only of the outer protective garments, but also of the entire set: outer protective clothing – underwear, is of great importance for the proper protection of the workers and providing them during their work with conditions approximating thermal comfort as closely as possible [1, 2].

The moisture that accumulates in underwear materials due to thermophysiological processes and release of significant amounts of sweat during work deteriorates the protective properties of protective clothing sets [1, 3]. This aspect should also be taken into account in order to ensure the safety of work in protective clothing under exposure to thermal factors, especially in extreme conditions.

The paper presents the tests results of resistance to thermal radiation and contact heat of the material systems consisting of knitted fabrics, dry or damp, and various materials designed for protective clothing.

Experimental
Knitted fabrics that can be used in underwear worn under protective clothing, as well as fabrics intended for protective clothing (cotton fabric with flame retardant impregnation: WB and glass aluminized fabric: WA) were selected for testing. For all the selected materials and their systems, protective parameters were tested in accordance with EN ISO 11612: 2015 [4]:

- radiant heat transfer index - RHTI\textsubscript{24} according to EN ISO 6942:2002 [5], method B with radiant heat flux density 20 kW/m\textsuperscript{2},
- threshold time according to EN ISO 12127-1:2015 [6], at the cylinder temperature 250°C.

Considering the hydrothermal conditions present under protective clothing (high microclimate humidity, presence of sweat in the liquid state) and the consequent moisture level in the underwear materials, heat transfer tests were carried out for the following material systems: underwear / protective clothing, for undergarments in dry and damp condition. The aim of the study was to assess how moisture present in the underwear materials influences the protective properties of the material system.

Results
Analyses of the obtained results related to the effect of moisture content in the tested knitted fabric samples on the RHTI subscript 24 radiant heat transfer index and the threshold time of the material systems were carried out. For most of the material systems, the protective parameters were found to deteriorate due to the moisture content in the underwear material (figure 1). The level of the tested parameters was dependent on the amount of the absorbed liquid and the type of outer fabric designed for protective clothing. A higher decrease in protective properties due to the moisture content in the underwear materials was found in the case of the material systems including aluminized glass fabrics than of those with cotton fabric. The above result may be due to moisture evaporation during exposure to radiant heat of a material system in which the outer fabric is characterized by a vapor permeability as opposed to an outer fabric material that does not allow permeation of water vapor and air (WA).

Figure 1. Results of the determination of the radiant heat transfer index under exposure to thermal radiation (20 kW/m²) for fabric systems: knit underwear (B-cotton, V/P-polyester viscose, P-polyester, N-aramide) in a dry and damp condition in an assembly with an outer protective clothing fabric (WB) in a dry state

Acknowledgments
The paper has been based on the results of Phase IV of the National Programme „Safety and working conditions improvement”, funded in the years 2017-2019, co-financed in the field of State Services by the Ministry of Family, Labour and Social Policy. The Programme coordinator: Central Institute for Labour Protection - National Research Institute.

Keywords: protective clothing, underwear, thermal factors, effect of moisture.

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INFLUENCE OF PERSPIRATION SIMULATED ON THERMAL HAND MODEL ON THE INSULATION OF PROTECTIVE GLOVES IN COLD THERMAL ENVIRONMENT

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Introduction
One of the important elements of ensuring the workers protection against heat loss due to low temperature is the use of suitable protective gloves [1,2]. The protective gloves designed for work in cold environment should be characterized by an appropriate level of thermal insulation, which depends on the glove construction. Sweating has the high impact on changes in thermal insulation of personal protective equipment [3].

Experimental
The aim of the study was to evaluate the thermal insulation of protective gloves, under conditions of simulated perspiration (5 g/h), taking into account the different ambient temperatures of the cold working environment. Measurement of thermal insulation was made using thermal hand model according to EN 511:2006 [4]. Temperatures in the climate chamber were modeled to reflect the working conditions, ie, 10°C, 5°C, 0°C, -10°C [2]. Two types of gloves of different design (5-finger gloves and mitts) were used in the study. Materials used in mitts glove construction (Variant 1) are: PU-coated polyamide (220 g/m²), 100 % polyester microfleece (130 g/m²), and 100 % polyester nonwoven (110 g/m²). Materials used in the 5-finger gloves construction (Variant 2) are: PU-coated polyester (315 g/m²), laminate– PES/PES/PES (350g/m²), and composite of wool (87%) and polyamide (13%) (440g/m²). The reference measurement was the thermal insulation of the protective glove without simulated perspiration.

Results
Based on the results of thermal insulation measurements carried out on 2 variants of protective gloves, it was found that the inclusion of perspiration reduces the value of this parameter. (Table 1).

Table 1. Decrease of thermal insulation during simulated perspiration [%].

<table>
<thead>
<tr>
<th>Modeled temperature [°C]</th>
<th>Protective gloves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variant 1 (V1)</td>
</tr>
<tr>
<td>10</td>
<td>26%</td>
</tr>
<tr>
<td>5</td>
<td>24%</td>
</tr>
<tr>
<td>0</td>
<td>27%</td>
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<tr>
<td>-10</td>
<td>33%</td>
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</table>
Simulated perspiration reduces the performance level in terms of thermal insulation. In the case of mitts glove, there is a decrease from 3rd to 2nd performance level, and in the case of five-finger gloves from 2nd to 1st performance level.

**Acknowledgement**

The paper is based on the results of COLDPRO project: ‘The use of active ecological mineral compounds in the production of cold-protective gloves and footwear’ funded in the years 2015-2018 by the National Centre for Research and Development.

**References:**

First responders and other professionals have to wear protective clothing while fulfilling their professional tasks. It is a known fact however, that protective clothing creates a barrier for body heat and moisture transport to the environment causing significant discomfort. During physical activity, up to 80% of the heat is dissipated by the evaporation of sweat [1]. As the sweat cannot evaporate in the warm and damp microclimate of protective clothing the core temperature rises [2][3], resulting in decreased mental focus and significant impact on the physical state [1]. For these reasons, many groups and companies are currently developing cooling garments. Passive cooling garments with hydro-crystals [4], superabsorbent polymers [5], or just water are being developed and these can be useful for short-time use. At the same time research shows active cooling garments equipped with ventilators show promising cooling results that can be applied during longer activity [5, 6]. However, those previous solutions remained at development level. Recently, Teijin has been developing an active cooling vest solution for firefighters and first responders, who are facing the heat stress issues under stressful conditions during the operations or from the surrounding environment.

In this presentation we describe the development journey of Teijin and its partners with the active cooling vest. The active cooling-technology was extensively studied and the user centered design and system integration was the major aim of this research. After multiple prototype iterations, the cooling vest effectively reduces body temperature and heart rate through sweat absorption, quick drying and moisture permeability. The electric fans pull in outside air for up to eight hours. The vest is lightweight, has a flexible fit and the inner layer fabric is optimized for sweat absorption, quick drying and moisture permeability. These unique features add high comfort to the body during extreme firefighting operations, which can contribute to a better flow of firefighting operations. Furthermore, the outer layer of the cooling vest is made with a heat-resistant, flame-retardant meta-aramid fiber. This way the garment provides an additional protection against flashover, or when the flames penetrate the turnout gear [7, 8].

Concluding, the developed prototypes demonstrated the intended functionality, and led to positive feedback from the involved firefighters. The current developments will be followed up by field trials later this year to learn in which scenario the cooling garment can be most effective for the prevention of heat stress.

Keywords: cooling, firefighter, user, product development, system integration

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ADVANCED FIRE SHELTERS FOR WILDLAND FIREFIGHTERS

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Introduction
Fire shelters are the last line of defense for wildland firefighters. This presentation will describe a major research project that developed advanced wildland fire shelter constructions designed to improve insulation against direct contact with flames in burn-over events. This research also developed new laboratory testing technologies for evaluating fire shelter heat blocking materials and for testing shelter prototypes in full-scale fire exposures. It compared the performance of the advanced prototypes with the currently used shelter in lab tests, and in prescribed burns conducted at different locations in the U.S. and Canada.

Experimental
Prototype fire shelter constructions were tested in both static and dynamic thermal protective performance (TPP) tests. A new full-scale testing facility called PyroDome™ was developed to evaluate the thermal protective performance of fire shelter prototype in intense exposures (84 Kw/m²) to turbulent flames.

Figure 1. Testing Wildland Fire Shelters Resistance to Flame Exposure in PyroDome™

Full-scale lab testing was followed by field tests in prescribed burns conducted in southeastern and western United States and in Canada. Performance data were analyzed to identify the best performing prototype materials and to establish correlations between laboratory assessments and shelter performance.

Results
The novel fire shelter constructions were shown to significantly improve on existing fabric technology (fiberglass and silica fabrics with aluminized outer surfaces) in fire blocking performance. Advanced fire shelter options were capable of providing 2-3 times better flame impingement survivability than the currently deployed fire shelter.
This research contributes to improve wildland firefighter safety by developing high performance fabric systems for fire shelter construction. It provides fire shelter manufacturers with more advanced materials options, as well as an enhanced technical basis for evaluating fire shelter materials alternatives. The testing database will contribute to future revisions of standards for wildland firefighter protective gear and provide systems-level testing options that can be used to assess future shelter design changes.

Acknowledgement
The United States DHS FEMA Assistance to Firefighters Grants (AFG) Fire Prevention and Safety Program funded this research.

Keywords: Wildland Fire Shelters, fire test methods, firefighter protective gear, wildland firefighting
HEAT TRANSFER CHARACTERISTIC BY WATER CONTENT OF OUTER AND THERMAL LINER IN FIREFIGHTER CLOTHING AGAINST ORDINARY AND ROUTINE HEAT EXPOSURE

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Introduction
Fire protection clothing is made up of three layers of fabrics: outer layer, moisture permeable waterproof layer, thermal barrier layer. The re-outer layer (outer material) is subjected to water repellent treatment to prevent infiltration of fire extinguishing water and the like, but water repellency weakens due to rubbing, deterioration, adhesion of dirt between the fabrics, and eventually contains water. Also, the heat shielding layer closest to the skin is sweated during activity, water is extinguished by fire extinguishing water entering the inside of the clothes. If the fireproof clothing receives heat generated by a fire during the fire extinguishing activity in the state that the outer layer of the fireproof clothing and the heat shielding layer are contained in the water, the water vaporizes into water vapor, moves in the cloth, and when it touches the skin Heat injury to water vapor. This is condensation heat transfer. Although water is effective as a medium for depriving heat during extinguishment, it is a negative medium that promotes burns in heat conduction inside the fire protection clothes. In this research, we experimentally verified the relationship between moisture content and burn injury risk of the outer layer and the heat shielding layer by changing the heat flux received by firefighting clothing.

Experimental
For the test sample, a three layers firefighter fabric in Japan (both the outer and the thermal liner: m-aramid: p-aramid = 90: 10, moisture barrier: e-PTFE) was used. The outer layer was no water repellency to control the moisture content easily. The sample size was 140 mm x 140 mm. To prepare various moisture content for fabrics, mass of the outer and the thermal liner was measured, and the sample fabric was placed in a zippered plastic bag, distilled water of a mass corresponding to the set moisture content was added. Then, sample was put it in parallel on the desk and keep it for 24 hours. The experimental apparatus consists of a cone heater specified in ISO 5660[1], a sample holder, movable base, and a sensor section. The test sample was tensed and fixed with a steel frame and the copper sensor specified in ISO 9151[2] was used to measure the temperature rise of the copper sensor due to the heat transmitted through the fabrics. For the experiment, the moisture content was 0, 20, 50, 75, 120 wt.% for the outer layer (Case (a) in Figure 1), 0, 20, 50, 75, 100 wt.% for the thermal liner (Case (b) in Figure 1) and heat time for experiment was 60 seconds (Excluding 5 kW/m² of 3-layer fabric). The incident heat flux to fabric was 5, 10, 15, 20, 25, 30 kW/m². Experiments were also conducted on a single layer fabric (outer fabric only, Case (c) in Figure 1). This experiment was evaluated in accordance with ISO 9151[2] using a heat transfer index (HTI) which is an evaluation index of heat conductivity test of fireproof clothing fabric.

Results
Figure 1 compares the results of HTI under each experimental condition for each heat flux received by each fabric. The tendency of burns shows 10 kW/m² and 20 kW/m² which are easy to compare. Each symbol represents that a diamond in the graph is HTI₁₂, A square is HTI₂₄, a
circle is HTI_{24} - HTI_{12}. Increase of HTI on the vertical axis means that the time for the wearer to start feeling pain and the time for burn injury increases. When outer layer of three layers (three layers test) was wet, HTI_{12} was shorter than that of dry condition regardless of the magnitude of the heat flux received. HTI_{24} and HTI_{24} - HTI_{12} were extended as the time to the second degree burn injury. Also, when the water content is 120 wt.%, to both lower than the results of the dry condition. Next, when thermal liner of three layers (three layers test) was wet, all three HTIs shortened regardless of the magnitude of the heat flux received. If the moisture content was 50 wt.%, HTIs value were the most reduced. However, when the moisture content is 100 wt.%, the result was the same as dry condition. Finally, when outer fabric (one layer test), all HTIs shortened regardless of the magnitude of heat flux received. This is almost the same result as the condition which the thermal liner of three layers was wet. HTI_{24} – HTI_{12} at 20 wt.% moisture content was slightly longer than dry. At the moisture content of 120 wt.%, both HTI_{12} and HTI_{24} were close to the data of dry condition. The result of only outer layer (one layer test) was similar to the data thermal liner of three layers (three layers test) was wet. The characteristic of steam burn was found to be changed depending on the position of the water-containing layer was outside or inside than the moisture barrier of three layers fabric.

Figure 1. Heat Transfer Index (HTI) comparison by various water content (Hydrous) and heat flux

Acknowledgement
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Keywords: Temperature measurement; Steam burn; Heat transfer index; Moisture content.

References:
COMPATIBILITY OF FIREFIGHTERS’ PROTECTIVE CLOTHING AND OTHER PPE

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Introduction
When following a risk assessment firefighters have to wear personal protective equipment (PPE) to protect them from hazards and guarantee their safety. Health and wellbeing, it is important that there is no negative interaction between wearers and the (items of) PPE. Firefighters often use different items of PPE to protect themselves against various risks, such as heat and fire, falling objects, smoke and chemicals. Besides protective clothing, they mostly also use helmets, balaclava’s, facemasks, protective gloves and boots. Sometimes they use fall arrests. All these protective items are certified according to (inter)national standards (EN and/or ISO), directives and regulations. However though mostly certified items are used, this will not guarantee optimal protection of the firefighters, because the combination of items of PPE is not seen as a personal protective system and not certified as such. For example if a balaclava is used for prevention against smoke particles and is worn under the face mask leakages can occur, leading to possible inhalation of smoke particles. To overcome these kind of negative interaction of wearing different items of PPE it is important that compatibility of PPE items is taken into account.

Methodological framework
In ISO Technical Committee 94 ‘Personal safety – Personal protective equipment’ a special task group (TG) was initiated on ‘Compatibility of PPE items’. Compatibility becomes an issue when different types or combinations of PPE of an ensemble or different performance levels within an item of PPE are worn at the same time. This is because different levels of performance could result in varying levels of protection. This could also mean that each item of PPE may not functionally interface with each other or may interfere with other items of PPE. This may lead to a reduction in protection and/or restrictions provided by the PPE which may impact on the ability to carry out the tasks. The assignment to the TG is to describe the interface areas and to develop test methods for quantifying the compatibility from top to toe, inside out, but also between integrated electronics into the PPE items. The test methods should include:

- compatibility between items of PPE and/or
- compatibility of PPE with the wearer and the use environment and/or
- compatibility with integrated sensors and other associated (electronic) devices, e.g. communication, environmental monitoring and physiological monitoring devices.

All combinations of PPE must be tested under reproducible and realistic circumstances. Test persons perform a series of practical tests (practical performance tests) that demonstrate the compatibility of items of PPE and ensembles measured against a previously defined set of performance criteria. These tests contain testing of the interfaces between PPE items of at least between:

- head/skull protection and breathing protection, hearing protection, eye/face protection and torso protection,
- breathing protection and hearing protection, eye/face protection and torso protection,
- torso protection and legs protection, hand protection and fall protection,
• fall protection and breathing protection,
• legs protection and feet protection,
• under clothing and outer clothing,
• gloves and mittens,
• boots and overboots.

If an item of PPE is worn for protection against a specific risk, the use environment can also be a limiting factor for wearing the item(s) of PPE e.g. narrow spaces, slippery surfaces or climatic conditions. Therefor also general practical performance test methods need to be described.

Sensors and or actuators should be reliable and may not hinder the wearer in its functioning with the PPE items nor may (other) PPE items hinder the transmission of input signals of the sensor or (sensory) output signals of the actuators to the wearer. Necessary energy supply (e.g. batteries) for the sensors and actuators may also not hinder or harm the wearer. If applicable test methods and minimal requirements should be described. To perform the tests, the intended user population and critical tasks shall be taken into account. Bröde et.al. [1] give clear guidelines for selecting the amount of test persons.

**Discussion and conclusions**
Compatibility between items of PPE will always be a difficult issue, because different manufacturers have to comply to standards and taken into account other products than their own products. However for the end-users compatibility between items of PPE is an elementary safety issue. At the moment compatibility standards are under development [2,3], There is an urgent need for firefighters to participate in cooperation with manufactures and test houses in standardisation committees for the development of clear compatibility standards to guarantee proper functioning of all worn PPE items on one single firefighter during performing of his/her tasks.

**Acknowledgement**
The authors gratefully acknowledge Russel Shepard, convener of ISO/TC94 and the fruitful cooperation with the colleagues within ISO/TC94/TG01.

**References:**
HIGH THERMAL RESISTANCE BOOTS TO IMPROVE FIREFIGHTER SAFETY

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¹Centro de Estudos sobre Incêndios Florestais, Coimbra, Portugal
²Lavoro Europe

Introduction
In the summer of 2013, after the death of several Portuguese firefighters due to the lack of foot protection in forest fires, the authorities concluded that it was necessary to prepare footwear with a higher degree to fire resistance. In this context, the Centre for Forest Fire Studies (CEIF) proposed to Lavoro a partnership to produce a boot capable of withstanding thermal impacts similar to those experienced in real fires.

Experimental
Lavoro sought to produce a boot that would mitigate cases where firefighters endanger their physical integrity by using appropriate professional footwear according to the law, but suitable for the extreme real conditions they face. In order to guarantee maximum protection to the user, Lavoro gathered the best materials and technologies available:
LEATHER - Water resistant, water repellent and breathable, with 2.2 - 2.4 mm thickness.
LINING - Sympatex technology waterproof, breathable and with great resistance to abrasion.
FORM - Developed according to the podological standards, to enhance comfort, even in prolonged use and uneven ground conditions.
TOE CAP - Protection in steel, anatomically designed to avoid digital conflicts. Resistant to 200 joules, which includes outer reinforcement.
PROTECTION PAD - Drill-resistant insole (1100N) in Kevlar, allowing full flexibility.
CLIMA CORK INSOLE - Inner cork and naturally tanned leather insole (Chromium Free), which provides excellent thermal comfort in any season. The cork regulates temperatures and humidity, favoring the health of the feet.
REFLECTORS - High-visibility reflectors for detection over long distances.
SOLE - Vulcanized rubber directly to the cut, in order to guarantee the stability of the adhesion even in extreme conditions.

Results
After several tests carried out by research centers associated with the University of Coimbra, our Fénix article, which was also tested by five fire brigades in real working situations, presented a high resistance to thermal impacts similar to forest fires (500 degrees Celsius) with good conditions of integrity for its user, even higher than the standards that determine the requirements to be observed by individual firefighter protection equipment.
FÉNIX represents design and quality, ergonomics, comfort, easy to put on and take off, high adhesion, mechanical and thermal resistance, impermeability, reflectivity and protection of life. Four years later, Fénix, which already protects the feet and life of more than 10,000 Portuguese firefighters, can and should be available to firefighters in other countries…

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CATEGORIZATION OF FABRICS USED IN FIREFIGHTERS’ CLOTHING BASED ON THEIR THERMAL PROTECTIVE AND THERMOREGULATION PERFORMANCES

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Background
Fabrics used in firefighters’ clothing should provide high thermal protection from fires [1]. Additionally, these fabrics should exert low thermal stress to firefighters through proper thermoregulation i.e., by properly dissipating the metabolic heat and sweat vapour from firefighters’ bodies to the ambient environment [2]. By controlling the fabric properties, thermal protective performance of a fabric can be increased. However, a fabric with very high thermal protective performance results in very low thermoregulation performance. As these performances are inversely related, a categorization tool based on the thermal protective and thermoregulation performances could guide the clothing manufacturers and/or fire stations’ clothing procurement managers to select appropriate fabrics for the clothing based on their requirements. Nevertheless, no studies have been carried out in this direction yet. Present study aimed at categorizing fabrics used in the clothing based on the thermal protective and thermoregulation performances. The allocations of fabrics within the categories have been discussed based on their properties. Finally, this paper identified a trend among the categorized fabrics that can direct towards upgrading or developing for high performance fabrics.

Materials and Methods
A set of fabric systems (commercially used in firefighters’ clothing) of different fibre compositions and constructions (single- or multi-layered, woven and/or nonwoven, nanononwoven) was selected. Properties of the fabric systems (weight, thickness, thermal resistance, air permeability, evaporative resistance, sweat spreading speed of the fabric layer next to wearer skin) were measured using the standard test methods.

Thermal protective performances of the fabric systems were measured in terms of Heat Transfer Index (HTI24 in seconds) according to ISO 9151 at 80 kW/m². The HTI24 values were indexed by normalizing them within a scale of 0 (indicating low performance) to 1 (indicating high performance) and termed as Thermal Protective Performance Index (TPPI).

Thermoregulation performances of the fabric systems were measured in terms of Comparative Time to Heat Stress (cTHEST in minutes) according to ISO/FDIS 18640, which can also be interpreted as ‘Maximum Allowable Work Duration’. cTHEST values were indexed by normalizing them into a range of 0 (indicating low performance) to 1 (indicating high performance) and termed as Thermoregulation Performance Index (TRPI). Data from human trial indicated a linear correlation between TRPI of fabric systems and time to heat stress of firefighters’ (wearing the clothing made from the same fabric systems) exercising at 40°C ambient temperature and 30% relative humidity [2]. Thus, TRPI of fabric systems could indicate about the time to heat stress of on-duty firefighters for a particular ambient environment.

Clusters among the fabric systems were identified by implementing the TPPI & TRPI values in k-means clustering algorithm. Next, the systems were divided into categories using standard (EN, ISO) requirements & typical TPPI/TRPI values. The allocations of systems within
categories were explained based on the significant fabric properties affects performances. Performance trend among categorized fabrics was justified based on their manufacturing process.

**Results and Discussion**

The k-means clustering algorithm resulted in three clusters with representative centroids indicating typical TPPI and TRPI values (Figure 1). As per EN 469, fabric systems have two protection levels – Level 1: 9s ≤ HTI24 value < 13s (or 0.27 ≤ TPPI value < 0.45); Level 2: HTI24 value ≥ 13s (or TPPI value ≥ 0.45). And, Level 2 fabric systems are most likely used in firefighters’ clothing. Also, according to ISO 11612, fabric systems with HTI24 ≤ 4s (TPPI ≤ 0.05) cannot pass the standard to use for thermal protective clothing; so, these fabric systems can be called as non-standard (NS). Depending upon the typical TRPI value of each cluster (i.e. centroid value), thermoregulation performance of the fabric systems can be divided into: low (TRPI value < 0.52), medium (0.52 ≤ TRPI value ≤ 0.76), or high (TRPI value > 0.76). By considering the EN 469 and ISO 11612 requirements and the typical TPPI values, the fabric systems were categorized into Category 1 and Category 2 as shown in Figure 1.

**Figure 1.** Categorization tool for fabrics based on their thermal protective and thermoregulation performances (TP = Thermal Protection; TR = Thermoregulation; L = Low; M = Medium; H = High)

In this study, thermal and evaporative resistances were identified as significant fabric systems’ properties to directly affect the thermal protective performance. Weight and evaporative resistance were identified as significant fabric systems’ properties to indirectly affect the thermoregulation performance; whereas, sweat spreading speed was identified as significant fabric systems’ property to directly affect the thermoregulation performance. Furthermore, an important trend was observed that fabrics in Category 1 with high protective but low thermoregulation performances (TPHTRL) were manufactured by conventional technologies of converting fibres into fabrics (woven or nonwoven). However, fabrics in Category 1 with high protective but medium thermoregulation performances (TPHTRM) represented latest technologies (e.g. nanocomposite, smart finishes). So, this trend suggests a possibility for upgrading thermoregulation performance of fabrics from low to medium range using the latest technologies, while maintaining the same protective performance. It is also notable that fabrics in Category 1 with TPHTRH can give high protection along with high thermoregulation for firefighters. Nevertheless, no fabric belongs to this category yet. For the benefit of firefighters, it is desired to develop fabrics that can belong to Category 1 with TPHTRH.

**Conclusion**
Clothing factories can use the tool developed in this study for selecting fabrics with required performances while manufacturing firefighters’ clothing. This tool will also guide the fire station managers to procure appropriate fabrics based clothing for the better protection and comfort of their employed firefighters. In future, this study can be directed towards the development of new fabrics with high thermal protective and high thermoregulation performances.

Acknowledgement
The authors like to acknowledge DuPont, Switzerland for providing the fabrics and funding.

Keywords: firefighters’ clothing, thermal protection, thermoregulation, k-means clustering.

References:
HIGH MECHANICAL IMPACT RESISTANCE SAFETY BOOTS FOR FORESTRY OPERATIONS WITH BRUSHCUTTERS

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Introduction
Forestry work is among the activities characteristic of rural areas, one of the most dangerous and where there are many serious accidents. In previous years there have been accidents at the level of the lower limbs in forestry operations, particularly to the feet, which involved the use of brush cutters and other manual cutting tools, and thus require special safety measures. The most common accident causes using brush cutters are: projection of variable size particles, projection of steel fragments and projection of anthropogenic materials namely wires that are used in agricultural infrastructures such as in wire fences.

Experimental
Therefore, the Portuguese safety shoes manufacturer Lavoro proposed to Centre for Forest Fire Studies (CEIF) of ADAI a partnership in order to: test and validate different samples of material combinations available on the market (Kevlar, Dennyma, etc.) that could promote the manufacturing of footwear more resistant to the impact of sharp objects; test and evaluate if the different types of material samples perforate or not using steel projectiles, with distinct forms and sizes, fired at different velocities (between 200 and 400m/s) - standard (ISO 20344:2011). A new and original structure was built and a methodology was developed to evaluate the different materials used in the manufacture of the boot. The structure and methodology were specifically developed and used to perform the tests. The estimated velocity in the projection of metal particles which are released from the disks of the brush cutters in forestry operations will be approximately 200 m/s - it was simulated at laboratory with speeds of 200 m/s and 400 m/s and in general the materials had a good performance.

Results
After the results achieved, the final product (THOR boots) was created and it includes the following specifications: specially designed to protect against flying objects when using a brush cutter or a trimmer; tested to objects launched at a velocity up to 300m/s; manufactured from very strong hardwearing material; lightweight cool and comfortable to wear; and smooth and padded panel on the flexing back part zone. Thor boots have a unique system of internal protection against cuts and perforations, duly tested by independent laboratories.

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4. Lei de Bases da Política Florestal – Lei n.º 33/96, de 17 de agosto.
PMIA REINFORCED GRAPHENE OXIDE AEROGELS AS PROMISING THERMAL INSULATION MATERIAL FOR FIREFIGHTING PROTECTIVE CLOTHING

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Abstract
Aerogel composites as porous, low-density materials are being widely used in the fields of thermal insulation, energy storage, waste disposal, and so on. Among them, Graphene oxide (GO) aerogels are very attractive due to their ultralight density, low thermal conductivity, high extinction coefficient, etc. [1] Their thermal conductivity can be as low as 0.0126±0.0010 W·m⁻¹·K⁻¹, much lower than that of PMIA thermal liner (~0.035 W·m⁻¹·K⁻¹). It can be envisaged that the thermal protective performance of firefighting protective clothing (FFPC) can be greatly enhanced by introducing GO aerogels into its multi-layered structure. However, the GO aerogels are brittle to some extent [2], and tend to collapse or deform during the processes of imbibition and reheating. Therefore the GO aerogels require structural reinforcement before practical applications.

In the present study, poly (meta-phenylene isophthalamide, PMIA) short fibres that have excellent thermal resistance, flame retardant and good mechanical properties are employed as the reinforcement of GO aerogels. The PMIA reinforced GO aerogels are firstly prepared by adding a certain amount of PMIA short fibres in GO suspension before the typical self-assembly reduction with ethylenediamine (EDA) and the following freeze drying process [3], as shown in Figure 1. Then, the morphology, mechanical performance, thermal properties and shape stability of the prepared aerogels were characterized by SEM, TG, WCA, etc.

Figure 1. Schematic illustration of the preparation of compressible GO aerogels reinforced by PMIA.

The prepared aerogels show many interesting properties, such as ultra-lightness, hydrophilicity, enhanced mechanical strength, and so on. The density of the PMIA reinforced GO aerogels is calculated to be 5.5~13.2 mg·cm⁻³, varying with different fibre contents. Compared with that
of the widely-used PMIA thermal liner (~120 mg·cm$^{-3}$), their potential application in FFPC will be very attractive. Their low density here is attributed to the restricted shrinkage during aerogel preparation and the resulting porous structure with a large amount of air trapped inside. As a result, their low thermal conductivity is achievable. In addition, the reinforced GO aerogels also have strong water absorption ability, and do not suffer deformation during imbibition and subsequent oven heating. These outstanding properties make the PMIA reinforced GO aerogels very promising for thermal insulation applications. Potential use as superior thermal liner for FFPC is being investigated in our on-going study. With the development of technology, their relatively high cost existing now will no longer be an issue in the future.

References:


THE DEVELOPMENT OF THERMAL PROTECTION PERFORMANCE EVALUATION DEVICE FOR FABRIC WITH SIMULATED FIRE FIELD AND HUMAN BODY ENVIRONMENT

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Introduction
From the view of the world, the fire caused immeasurable loss, there are thousands of firefighters were severely burned or even killed during a year in fire rescue. It is necessary to isolate fire field high temperature through fire-proof suit to ensure that firemen are not burned under the condition of normal rescue in the environment of high temperature fire (1). Thermal protection performance is one of the most important functions of the fire-proof suit, which determines the protective effect of the fire-proof suit. The real and effective evaluation of thermal protection performance of fire-proof suit is very important for its use.

In today's world, there are many evaluation methods for the thermal protection performance of fire-proof suit. The fire resistance of textiles is evaluated by using the vertical combustion method, 45 degree tilt method and the limit oxygen index method. The Radiant Protective Performance (RPP) test method is used to evaluate the radiation protection of the fabric. The Thermal Protective Performance (TPP) test method is used to evaluate the comprehensive protective performance of heat radiation and heat convection of fabric. The test method of Thermo-man is used to evaluate the protective degree of a complete set of clothing to firemen (2).

There are some defects in these methods and devices at present. The vertical combustion method, the 45 degree tilt method and the limit oxygen index method can only evaluate the fire resistance of the fabric, but they can't evaluate the thermal protection performance of the fabric. The current TPP, RPP test device can't effectively simulate the real situation of the human body and the fire field, can't simulate human contact fabric tactile fee, can't effectively test the temperature on the diffusion of fabrics in the fire, can't represent the long thermal protection performance of the fabric in the environment of high temperature and strong heat flow and fire field (3). The experimental conditions of Thermo-man are higher, the experimental device is more complex and the cost of the experiment is too high.

In this paper, a new thermal protection performance of the fabric evaluation device is discussed.

Experimental
The design sketch of the device is shown in the following diagram(Figure 1). This device simulates the fire field - the fabric - body system, similar to the human body wearing fabric, to test the thermal protection performance of the fabric under the condition of the real fire field. This device uses a flame generator to produce a flame of fire and forms a real fire environment in the chamber. Simulated human body temperature environment in the cavity cover by heating device. The device uses tactile feeling of simulating human contact fabric with intelligent finger
contact fabric. This device uses visual system to monitor the damage of fabric during the experimentation. This device uses a temperature testing system to monitor the surface temperature of fabric, flame temperature and the transmission of temperature on the fabric sample during the experimentation.

Figure 1. Thermal protection performance of the fabric evaluation device

Results
This device not only realizes the real and effective evaluation of fabric thermal protection performance, but also can well characterize the long thermal protection performance of fabrics in high temperature, strong heat and bright fire. The evaluation results are more effective, the evaluation index is more comprehensive and the evaluation process is more simple and convenient. The research and development of this device has effectively compensated for the shortcomings of the previous device and has high scientific research value.

Acknowledgement
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References:
THE CONTAMINATION AND DECONTAMINATION OF FIRE FIGHTING GARMENTS –LABORATORY TESTS

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Introduction
Fire fighters are exposed to a wide spectrum of chemical substances occurring in different forms. Some of those agents absorb to firefighters’ garments, from which they can evaporate into the breathing zone of workers after rescue tasks (1). Also contaminated garments easily contaminate fire fighters’ skin, causing dermal exposure and possibly oral exposure (2). The goal of our study was to find out, what kind of chemicals can be found in firefighting garments after normal overhaul and how we were able to decontaminate PAHs from the garments with a standard cleaning protocol.

Experimental
The Institute for Safety delivered ten contaminated and one clean firefighting garments to be analyzed in Finland. The Finnish Institute of Occupational Health was responsible for pretreatment and analysis of the samples taken from the inner layer of the neck as well as from all layers of the stomach and back of the firefighting garments. The analyses included volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs) and water soluble ions. The National Institute for Health and Welfare in Finland analyzed the garments for perfluorooalkyl acids (PFAAs) and dioxins (PCDDs/PCDFs)-compounds. A sub-contractor of the Finnish Institute of Occupational Health was responsible for cyanide analyses. Diversey Finland Ltd took care of the washing procedure of the garments. The garments were washed at the brand new Finnish fire brigade in Turku according to the instructions given by IPV.

Results
The background concentrations of the garments were analyzed from the clean garment in phase I of the study. The probable locations of contaminating substances in different layers were characterized from contaminated garment 1 in phase II of the study. PAHs, VOCs and SVOCs accumulated in the middle layers of garments, while water-soluble ions seemed to accumulate in the inner layers. The measured concentration of PCDDs/PCDFs and PFAAs compounds was highest in the upper layers. The variation of the concentration in the most probable location of the garments were analyzed in garments 2-10 in phase III of the study. The extent of contamination in the garments was estimated by calculating the average concentration of PAHs at different location in the garments. The average concentration of PAHs in contaminated garments were 1.7 to 39 –fold higher than the respective levels measured in the clean garment. The highest average concentrations of PAHs were analyzed from the middle layers of the back and stomach. Some of the measured concentrations of benzo[a]pyrene, benzo[a]anthracene and benzo[b]fluoranthene exceeded the level for restriction of selling products by ECHA. The German AfPS (Committee for product Safety) has published requirements for evaluating PAHs from products and testing them for the GS Mark Certifications. Almost all of the measured...
PAHs concentrations of individual PAHs exceeded that value in the garments. The highest concentration of TVOCs were analyzed from middle stomach. The most common VOCs were mixture of aliphatic hydrocarbons, phenol, C12-C13-alcohols, benzoic acid, benzyl alcohol, 2-ethyl-1-hexanol, phenoxypyrropanol, decanal, hexadecane and geranylaacetone. The highest concentration of TSVOCs were analyzed from inner neck and the most common SVOCs were various alcohols, carboxylic acids, esters, hydrocarbons and glycol compounds. The highest concentrations of water-soluble acids were measured from inner neck. The highest water soluble residues reflected exposure to hydrochloric acid originating for example from the burning of PVC-plastic. The highest concentration of PCDDs/PCDFs and PFAAs were analyzed from stomach. The most common PCDDs/PCDFs were OCDD, OCDF, 1,2,3,4,6,7,8-HpCDD and 1,2,3,4,6,7,8-HpCDF. The most common PFAAs-compounds were PFOA, PFDA and PFDoA. The decontamination level of garments 2-10 were evaluated in phase IV of the study. The average concentration of PAHs in the garments after the washing procedure reflected poor washing efficiency. It seemed that PAHs transfer from more contaminated garments to less contaminated garments during the washing procedure. Comparison between batches showed that washing of three garments simultaneously resulted in a lower washing efficiency than washing of two garments simultaneously.

**Conclusion**

It is essential to test factors which have an effect on washing efficiency. For example how many garments is it sensible to wash simultaneously? Another point is to decrease the storage time of the garments as much as possible after contamination before washing. The third factor might be the drying procedure of the garments. If washing efficiency remains low after these improvements, other possible cleaning operations such as ozone treatment of the garment or liquid carbon dioxide –method should be combined with the current procedure. Or perhaps the current washing procedure should be replaced by these new methods altogether. Due to high measured concentrations from inner layers of the garment, it is necessary to reduce dermal exposure by using long sleeved and legged technical underwear to prevent direct skin contact with the garment. The neck has been proved to be vulnerable with respect to dermal exposure in many studies. To prevent that, an ergonomic and adjustable collar combined with the use of a hood, can decrease exposure significantly. Also particulate and vaporous contaminants try to enter the inside of the garment through the sleeves and legs. To prevent that, some sort of cuffs combined with special closures in sleeves and legs are needed in garments. It is also possible to reduce hand exposure very efficiently with under gloves made from cotton or leather. After rescue tasks already at the fire site, all contaminated firefighting garments have to be taken off and packed in self-melting bags, wearing under gloves and keeping breathing protectors (lighter) on until all contaminated equipment have been packed. Transportation of contaminated firefighting garments in self-melting bags should not be done in the crew cabin to prevent firefighters’ exposure during transportation to the fire brigade. This will also reduce firefighters’ exposure during maintenance of garments, because they can transfer the closed bags directly to the washing machine without opening them. Also replacing contaminated garments to clean ones already at fire site, prevent the contamination of the fire truck.

**Keywords:** Firefighting garments, PAHs, gross-contamination, exposure.

**References:**


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INTRODUCING A NEWLY DEVELOPED SMOKE AND PARTICULATE RESISTANT STRUCTURAL TURNOUT

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Introduction
Chronic exposures to toxic combustion products found in the fireground environment are believed to contribute significantly to the higher rates of cancers experienced by firefighters (1-5). When used during fire suppression and overhaul stages, the self-contained breathing apparatus (SCBA) protects the highly susceptible respiratory tract from the toxicants in smoke and soot (6). However, firefighters are still being exposed to hazardous vapors and particulates when smoke penetrates the interfaces in the turnout ensemble and deposits on the firefighter’s skin (1-5). The Department of Homeland Security Science and Technology Directorate (DHS – S&T) identified a requirement for improved interfaces of structural firefighter personal protective equipment (PPE) that will reduce the risk of skin absorption of harmful toxicants and carcinogens.

Experimental
In the scope of this research, North Carolina State University’s (NC State) Textile Protection and Comfort Center (T-PACC) has teamed with LION First Responder PPE, Inc. to develop the Smoke and Particulate Resistant Turnout (SRT), a new turnout ensemble system that will provide increased protection for currently vulnerable interfaces to smoke exposure and other fire ground contaminants. Research and development focused on the functional design and material implementation of the wrist, waist, and ankle interfaces of the current structural firefighter turnout.

Results
With two optimized functional design options, SRT implements smart interface designs and novel materials in key areas for the turnout coat and jacket, while retaining thermal comfort and thermal protection compared to existing turnout gear. Protection against smoke and particulates were evaluated through rigorous aerosol testing at the system level and has further demonstrated the material and design effectiveness of targeted areas for increased protection. The image (Figure 1) shows fluorescent particulates deposited on the skin after aerosol testing from wearing the current system compared to no visible deposition from the SRT ensemble. The SRT system, which is certified to NFPA 1971 Standard on Protective Ensembles for Structural Firefighting and Proximity Firefighting (2013 edition), could seamlessly be used to replace existing gear as well, as both donning and doffing protocols remain virtually identical.
Figure 1. Aerosol testing post-exposure comparison pictures - current system (left) and SRT – Concept 1 (right).

Acknowledgement
This study is supported by The Department of Homeland Security Science and Technology Directorate (DHS-S&T).

Keywords: Smoke, Particulate, Firefighter, Turnout.

References:
**Introduction**

In the last decade, there is the awareness that firefighters fighting a fire are working in an environment with contaminated air. What kind of contamination are they exposed to? Where are the contaminants, and in which concentrations? Research has been started up recently, so there is still little data available about this subject. Firefighters are using personal protective equipment, but do they use it correctly and over the total period of the intervention? Reduction of the exposure to risks (harmful contaminants, ....) is the basis of all OHS campaigns. Precautionary principles such as strict work hygiene practices are as important as work safety procedures, but have only recently been integrated in the SOP’s (Standard Operational Procedures) of a firefighter:

- Tactical thinking, reduce exposure to fire smoke
- All firemen exposed to smoke wear full intervention PPE (intervention suit, gloves, breathing apparatus of mask, …) during all stages of fire (including post fire overhauling)
- Ensure that there are good hygiene practices after exiting a fire incident, such as not entering the fire truck with contaminated clothing.
- Procedures for clean clothing at the site, or put contaminated garments in good closed bags – prevent cross contamination truck and other items
- Procedures for cleaning contaminated garments which is the topic of presentation, and only one (important) element of work hygiene.
- Taking a shower directly after returning to station.
- Have regular comprehensive health checks with a medical practitioner, appropriate to age, gender and family history

**Experimental**

Sioen participated in a study IWT150840, title “Development of innovative cleaning methodologies for fire fighter intervention suits”. During the 2 years we, together with our partner, RAPID Industry, tested several cleaning processes taking in account all kind of stains (blood, mud, greasy and oily stains) besides contamination with polycyclic aromatic hydrocarbons (PAHs, also named polyaromatic hydrocarbons). We tested and compared the results of different wet cleaning (modifications on the Sinner circle) and different dry-cleaning processes.

**Results**

We can conclude that with a correct wet cleaning process you can reach a high level of decontamination of the fire fighter suit.
SMART PPE - A KEYWORD FOR A SAFER LIFE

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Introduction
Based on known significant threats, like fires, road traffic accidents, major emergencies, natural disasters and terrorism, science and industry are confronted with a development and integration of smart PPEs which should ensure a high-quality protection while rescuing. In addition, implementing the smart PPE into daily activities of rescuers will become one of the priority tasks of their belonging organizations, also of the training protocols in the schools. Regarding the given a society of Rescue Services needs to strengthen links towards industrial developments with aim to ensure, not only safety in Europe, but also to support European industrial growth. The protection and safety of all those involved with, or affected by heat, fire, hot particles and other negative impacts from the environment, cannot be achieved by one specific type of smart PPE. Such a development and afterwards a serial production must be flexible and cost effective. Not only a functionality of textile materials is changing rapidly, also the treats from environment are becoming more and more complex. We need a modular solution of smart PPE.

Experimental
In this paper, an overview of smart PPE prototypes aimed for firefighters over Europe is given. These prototypes are developed using attaching (sewing or gluing) the electronic components onto or between the textile layers. From perspective of serial production such an approach is still not accepted as cost effective. Prototypes are not industrialized yet. This is bringing to the market barrier which is still not possible to overcome. Future studies need to be oriented into integration of sensorial (electronic) components on basic level of textile production, like weaving or knitting of sensorial yarn with multifunctional properties into a functional protective layer which can be manufacture as today’s fabrics or knitting. Further, the technology of confectioning the wearable electronics with advanced textile materials needs to fit with into a traditional production processes of PPE.

Results
Prototypes of smart PPE for firefighters differentiate in ICT functionalities, garment models, protective materials and alarming functions. Critical parameters are also the price on first place, weight, data protection of the users and unknown human comfort during the wear of smart PPE while exposed to harsh environment. Based on the gathered results and known strategy of Fire and Rescue Services in Europe, we need a robust and flexible solutions which can be adopted to changing requirements with little setup effort. One “Rescu-Net” platform developed in close collaboration within end users, industry and Service organization might be a flexible solution for all temporary known parameters and long-term Strategy for requirements of PPE in the future.

References


DECONTAMINATION OF FIRE INTERVENTION GEAR

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PROJECT OUTCOME : DECO2FIRE
The renewed lco2 - technology cleans, decontaminates, disinfects and re-impregnates fire fighting clothing, as the only existing environmentally friendly technology without damaging the clothing.

Introduction
The fire department worldwide is in a transitional phase with regards to occupational hygiene. The days when really dirty clothing was considered a testament to the experience and valour of fire fighters are long gone in most fire departments. New building materials involve new types of contamination, studies have shown the impact that contaminated PPEs have on the health of the rescue service providers. Occupational experts strive to achieve a minimum of exposure; 'clean work' forms part of the professional conduct of fire fighters nowadays. Adjusted intervention strategies (SOPs) ensure that unnecessary exposure to toxic products is avoided. However, it is impossible for fire fighters to avoid exposure to heavy toxic products such as VOCs, PAKs and dioxins, for example, when fighting fires in the home. In that case, the fire fighters’ only protection against these contaminants is his or her clothing and PPEs. The presence of high-quality and ‘clean’ personal protection equipment is therefore essential.

DECONTAMINATION
Carcinogenic substances can enter the body in three ways:
- Via the digestive system (gastrointestinal)
- Via the respiration system (inhalation)
- Via the skin (percutaneous)
The exposure via the first two manners can be minimised by adequately wearing respiratory equipment, the last – but for the fire fighter certainly not least – exposure can be minimised by adequately wearing intervention clothing (including gloves and a balaclava).
In order for a fire intervention suit to be classified as class 2 of the EN469 it must consist of multiple layers with an underlying membrane. Research has shown that the membrane not only keeps the wearer dry, but also acts as an additional protective layer against heat transfer and contaminants. The membrane remaining ‘intact’ is therefore essential at the time of the intervention!
How does it work? The membrane acts as some sort of reservoir. The moment the fire fighter is exposed to toxic substances, the reservoir fills itself with the toxic substances. The filling speed depends on the exposure duration, the type and concentration of toxic substances (for example fighting a kitchen fire versus a fighting a fire indoor).
For hygiene and health reasons, the reservoir, which is located near the body, must be emptied at regular intervals.
This is called DECONTAMINATION.
Scientifically formulated the decontamination of a fire intervention suit refers to the quantitative reduction of the carcinogenic and mutagenic substances that are mainly located on the membrane of the clothing up to the maximum permissible level.

Please note: scientifically, decontamination can never be expressed in a % reduction. The maximum permissible level is defined in the annex XVII of the REACH legislation. The inspection thereof on textile is done on the basis of the 'OEKO-TEX standard 100' certification system.

Fire intervention clothing forms part of the class 3 of the OEKO-TEX STANDARD with regard to toxicity, this refers to the toxic products that are most common, such as PAKs, and the level in which each individual type can be present in a quantity of 1 mg/kg and/or in its totality with a maximum of 10 mg/kg.

When taking samples of suits that were exposed to 1 x the manifest contamination or were exposed multiple times to non-manifest contamination, CENTEXBEL measured an average total PAK value in the membrane between 18 mg/kg and the 57 mg/kg, which on average is four times higher than the levels permitted on the basis of REACH.

The necessity of decontamination of firefighting clothing can therefore never be a point of discussion anymore! However, the major challenge is to remove the contaminants from the clothing (the membrane) without affecting the functionality (protection!) of the suit.

Decontamination with LCO2 is here the only appropriate solution. As LCO2 is an extremely fine liquid with a low viscosity, density and surface tension, it is able to clean through the membrane without damaging it. LCO2 is also an apolar substance, which means it naturally dissolves the contaminants extremely well.

Decontamination with water and detergents is not an option for this application; the programs necessary for full decontamination, i.e. at OEKO-TEX level, are extremely destructive for the clothing. Moreover, the clothing needs to be dried after each wet wash program, drastically reducing the life of the suit.

That is why the European Commission, via the VLAIO agency, has approved a project to find a solution in collaboration with a number of companies, Universities and CENTEXBEL, the notified body for textiles.

After one and a half years and dozens of tests, a renewed decontamination process was validated on the basis of liquid CO2. It is currently the only environmentally friendly technology in the market that manages to comprehensively and safely decontaminate, disinfect and re-impregnate firefighting clothing without affecting the functionality of the clothing.

**Conclusion**

LCO2 is a sustainable decontamination method that significantly increases the life of the clothing (in comparison to the wet wash decontamination) and this process also has a very small ecological foot print as it is low energy, requires no water, generates a low CO2- emission and no toxic products end up in the environment.

By regularly decontaminating fire intervention clothing with LCO2 and after each manifest contamination, your clothing remains safe and healthy. The clothing is free of toxic substances and micro-organisms, it is odourless and the protective qualities are guaranteed.
SMART FIREFIGHTER PROTECTIVE SUIT AND GLOVES

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Introduction

According to the statistics of the International Association of Fire, which is based on data from 35 world countries, 121 firefighters lose their lives whilst saving others and more then 82 000 firefighters were injured at fire incidents in 2012 [1]. Firefighter safety can be increased by introducing new smart textile-based protective suits, which not only protect the human body against the extremes of nature but also provide information about the firefighter’s state of health and his environment. Smart textile products have become a new area of dynamic R&D activities in Europe and in the USA. These products under development are based on integration of electronic modules into different types of clothing, predominantly into fashion, sport clothing and particularly into protective and health care clothing [2,3]. The smart textile products aim to be user friendly and to bring more comfort and safety.

Experimental

This work presents a research focused on a smart textile-based protective system which is intended to bring more safety to firefighters facing hazardous conditions. The system is fully integrated into a firefighter protective suit and it is able to monitor heart rate, to detect movements of a firefighter, to detect toxic and combustible gases in the environment and to measure temperature and relative humidity inside and outside of the suit. The protective system consists of developed integrated sensor modules, e-textile wiring harnesses, suit control unit (SCU), central commander unit (CCU), body area network and wide area network. The protective system also includes indoor and outdoor localization units. The indoor localization unit based on inertial sensors, which is placed on a protective boot, is dedicated for the remote tracking of firefighters in situations when GPS signal is missing.

The measured data are wirelessly transmitted over a wide area meshed network to the CCU, which is intended to be used by intervention coordinating officers, who are kept informed about an actual state of individual firefighters. In case that some monitored parameter oversteps pre-set threshold values, the SCU will automatically inform a firefighter by acoustic alarm about oncoming risk.

Results

In the frame of the research the following part of the smart textile-based protective system for firefighter were developed: WAN network with mesh routing protocol, micro docking stations for sensor modules, inertial indoor localization system, interconnection system, SCU, CCU control software including visualization, NO₂, CO, HR, movement detection, combustible gas, humidity and temperature sensor modules and IR temperature sensor module. The modules were integrated into the protective firefighter suit and glove. These modules are able to communicate with suit control unit over integrated bus system, while the SCU communicates over wide area network with the firefighter operation chief through control commander unit (CCU). CCU allows the data visualization of up to 12 firefighters, graphical threshold
visualization by traffic light approach, and announcing alarm to a particular firefighter. The developed smart firefighter protective suit performed well at the EMC test, washing resistance test, long-term stability and reliability testing. Very promising results were obtained in the field test in the flashover container in the firefighter testing center. Moreover, the smart protective gloves are certified according to ATEX and IECEx regulations. The suit was created as universal system, which can be equipped with bring new modalities and functions such as early warning system against burns, or blasts.

Figure 1. The smart firefighter protective suit and the glove.

Acknowledgement
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Keywords: smart textiles, smart protective firefighter suit, sensors, smart protective glove.

References:
VALIDATION OF CLEANING PROCEDURES FOR FIRE FIGHTER PROTECTIVE CLOTHING

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Introduction
Between fighting fires and responding to other emergencies, fire fighter personal protective equipment (PPE) is exposed to a wide range of toxic chemicals, biological pathogens, and other hazardous substances. Since these contaminants pose continuing exposure risks to fire fighters, turnout clothing is being more frequently washed; however, it is still not known if current or new cleaning procedures adequately remove such contaminants from PPE. To address this question, a 4-phase PPE research project was undertaken to identify and establish procedures for ensuring optimum contaminant removal from fire fighter PPE.

Experimental
The project included efforts for (1) identifying target contaminants, including both chemical substances and microorganisms; (2) developing techniques for contaminating clothing materials with selected chemical or biological contaminants; (3) investigating laundering procedures for removing chemical contamination, (4) assessing biological disinfection and sanitization procedures, and (5) developing overall guidance for the fire service in terms of handling and cleaning/decontaminating firefighter protective clothing. The principal aim of this effort was to develop a simple, portable approach that could routinely assess cleaning effectiveness.

Results
A cleaning verification methodology was developed that is capable of assessing cleaning procedures on surrogate samples as part of full scale laundering and sanitization processes for firefighter protective clothing. This process is illustrated in Figure 1. These procedures showed various levels of decontamination removal rates ranging from 40 to 100% depending on the contaminant type, and further showed \( \log_{10} 3 \) or better reduction of target bacteria for achieving sanitization, though significant microbial cross contamination occurred. The efficacy of the approach was demonstrated at several different cleaning facilities in the U.S.

The application of this approach was used for investigating various cleaning technologies and parameters. For example, increased temperature was found to improve removal of certain contaminants. Cleaning verification has been proposed as a future requirement for measuring levels of residual chemical and biological substances.
Figure 1. Proposed cleaning verification procedures using kit approach

Acknowledgement
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FIREFIGHTER SUIT WITH INTEGRATED SENSING CAPABILITIES AND REMOTE COMMUNICATIONS FOR ENHANCED SAFETY

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The development of sensing and monitoring technologies integrated into wearable devices has been explored in the recent years for many applications since it enables the possibility of having protective equipment with self-sensing and self-monitoring capabilities, while providing also critical environmental data monitoring where the equipment is operating. Personal and environmental wearable technologies, bases on flexible and lightweight printed electronics and embedded power systems, integrated into protective equipment enhances personal protective capabilities and environmental hazard monitoring, while concurrently maintaining functionality and mechanical robustness, design freedom of the equipment and assuring these wearables systems do not cause any hindrance to performance and comfort. One characteristic application for such monitoring systems, both personal/biometric and environmental conditions, via wearable smart systems are protective equipment for firefighters. Having protective firefighting equipment with integrated capabilities of biomonitoring the firefighter, as well as relaying information of surrounding environmental conditions in real-time, constitutes a clear safety and operational advantage and added value for the protective equipment. Within this scope, CeNTI and CITEVE have developed new integrated flexible and textile embedded wearable electronics for smart monitoring and sensing systems for firefighter suits. The protective firefighter suits were developed using new fire-retardant textile yarns that enhance fire resistance, while also having integrated sensing systems for both biometric and environmental conditions monitoring. Additionally, also remote communication and powering systems were integrated into/onto the textile structure of the protective equipment. Specifically, the suit is equipped with the external (environmental) and internal (suit) temperature monitoring and on-board processing system that determines the temperature differential between external and internal textile structure (temperature to which the human operative is exposed to). Additionally, there is also an integrated fall-detection and immobilization warning system, a GPS tracking system, integrated CO sensors monitoring hazardous concentration of CO, and on-board textile integrated lighting systems and haptic feedback warning systems that enable the firefighter to receive clear personal alerts. Furthermore, the system also integrates bidirectional communication with a GSM module that reports the geographic position, leading to a faster and more precise rescue in case of
emergency, but also enabling the coordination of small firefighting teams by integrating and processing the data received from each suit (Temperature gradients, CO concentration, geo-position, and alarms and distress warning management).

**Key Words:** protective firefighter suit, remote monitoring, integrated sensing
DEVELOPMENT OF TEST METHOD ON FIREFIGHTER GLOVES AGAINST HEAT AND ITS EVALUATION OF CURRENT PRODUCTS

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Introduction
During fire fighting activities, the hand holding the nozzle is located in front of other parts of the body against the flame. Therefore, the risk of burn injury is relatively high. Currently, heat resistance tests of firefighter gloves are carried out on glove fabrics with ignitability / heat resistance (convective heat / heat transfer from radiant heat). However, since the joint part of the finger on back side compresses the fabric when the hand is holding the nozzle, it becomes necessary to evaluate the heat resistance more practical to the actual use by adding tension/compression of the fabric. The objective of this research is to make evaluation method considering the actual use of wearing gloves and to re-evaluate the heat resistance on current firefighter gloves.

Experimental
Figure 1 (left) shows the pressure sensor used in this research, and Figure 1 (right) shows the relational expression of the inverse value of the measured resistance and the load. In this study, by measuring at a narrow place inside the glove, by measuring the local high pressure drop by the joint part of the finger, a thin film type pressure sensor of φ 5.6 shown in Figure 1 (left) (FSR® 400 Short, Interlink Electronics) was used. For the calibration, a load was applied with a weight of 0 g to 480 g having the same diameter as the sensor surface, and the resistance value of the sensor 60 seconds after the start of measurement was measured.

Heat resistance evaluation with tension / compression of the fabric was carried out using the test apparatus shown in Figure 2. Using a cone heater specified in ISO 56601), the incident heat flux on the sample was measured at 5, 10, 20, 40 kW/m² using a water-cooled heat flux meter (GTW-10-32-485A, Medtherm Corp). Temperature measurement was carried out using a cylindrical copper calorimeter2) (T-type thermocouple (TT-T-36-100, OMEGA) with copper plate thickness $t = 1.6$ mm, $\phi$ 0.13 mm). As shown in the right part of Figure 2, the center of the test fabric was wound around the cylindrical part of the test fabric and the both ends of the fabric were fixed to the lower surface of the laboratory jack, then the test fabric was pushed up and pressure between the fabric and the calorimeter was generated. To check the load generated between the test fabric and the copper calorimeter, a pressure sensor similar to pressure measurement on fingers was installed and the height of the jack was adjusted. The load conversion value of the pressure sensor 1 minute after the start of pressurization was adjusted to reach the target value ± 1%.

The glove size of subjects was determined from measurements of hand length and palm girth using two kinds of firefighter gloves (K-TFG5NV and K-TFG 7NV, Tombo Corp.), with 5 subjects' left index 1st finger and 2nd finger. As shown in Figure 1 (left), pressure gauge is attached to the second joint of the 1st finger and the 2nd finger as shown in Fig.1 (left), then fire gloves are attached, the resistance value of the sensor 60 seconds after gripping is measured 5 times, and the average value is obtained. Using the calibration formula of the reciprocal of the resistance value and the load in Figure 1 (right), the load used for the experiment was calculated.
(Table 1). The load value was decided as 0, 50, 133.3, 216.7, 276.2, 355.6, 466.7gf based on the result of the pressure measurement, and the corresponding voltage was set to 0, 1, 2, 2.6, 2.9, 3.2 and 3.5V.

Results

Figure 3 shows skin burn evaluation by heat transfer index (HTI) of ISO 9151 with the load applied to the test fabric with incident heat flux (5, 10, 20 and 40 kW/m²). HTI_{24} and HTI_{12} are indices corresponding to 2nd degree and 1st degree of skin burns, HTI_{24} - HTI_{12} is the time spent from 1st degree to 2nd degree of skin burns, respectively. When the heat flux is 5 kW/m², each HTI decreases as the load applied to the specimen increases, and it is found that it reaches a constant value at 216 gf. It is believed that the multilayer fabrics of the firefighter glove was compressed by the load and the air in the fabric was lost. For incident heat flux at 10 kW/m², 20 kW/m² and 40 kW/m², the same characteristic were observed.

In this research, attention was paid to tension and compression of the firefighter glove fabric when the glove were worn and hand was held. In order to reproduce tension and compression of the fabric with a test apparatus, the pressure was measured with a thin film type pressure sensor and converted into a load applied to the fabric. When load was applied, the heat transfer of firefighter glove fabric decreased linearly, and became constant around 216 gf. This experiment revealed that fire gloves get thinner by pressure and heat transmission get more. In addition to the heat resistance test on fabric, it shall be considered that the heat resistance test of the firefighter gloves can be conducted with loading.

<table>
<thead>
<tr>
<th>Pressure sensor for internal pressure measurement (left) and calibration chart of sensor output (right).</th>
<th>Compression test instrument for thermal transmission of firefighting glove; heating system (left) and loading system (right).</th>
</tr>
</thead>
</table>

Figure 3 Effect of load on heat transfer index (HTI) with heat fluxes; (a) 5 kW/m², (b) 10 kW/m², (c) 20 kW/m² and (d) 40 kW/m². Orange blue and green dots represent HTI_{24}, HTI_{12} and HTI_{24} - HTI_{12}, respectively.

| Table 1 Result of load measurement with firefighting gloves. |
|---|---|---|---|---|
| Glove | K-TFG5NV | K-TFG7NV | \( y = 0.0005x \) | \( R^2 = 0.9713 \) |
| Finger | 1st Finger | 2nd Finger | 1st Finger | 2nd Finger |
| A | S | 221.8 | 330.8 | 209.5 | 199.0 |
| B | S | 250.5 | 475.4 | 349.7 | 359.6 |
| C | S | 339.1 | 398.0 | 238.8 | 230.8 |
| D | M | 245.2 | 185.2 | 290.7 | 382.9 |
| E | M | 75.1 | 221.6 | 93.4 | 174.9 |
| Mean (gf) | 220.4 | 273.2 | 212.4 | 252.0 |
| SD (gf) | 113.3 | 174.1 | 92.7 | 89.6 |

Acknowledgement
This work was supported by JSPS KAKENHI Grant Number JP15H01789 and JP16H03133 and research grant of Uchida Memorial Foundation of Japan Association for Fire Science and Engineering.

**Keywords:** Temperature measurement; Firefighter Glove; Heat transfer index.

**References:**
PPE FOR PROTECTION AGAINST PESTICIDES: DEVELOPMENT OF SURROGATE TEST CHEMICAL

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³BASF Limburgerhof, Germany

Introduction
Prowl ® 3.3 EC, a commercially available product registered in the United States, is the test chemical used for ISO 27065 [1]. The selection of the test chemical was based on studies conducted with several formulations [2]. A commercial product was used since a surrogate could not be developed due to limited resources and expertise in pesticide formulation when the standard was initially published in 2011. In 2016 decision was made at the ISO meeting to transition from a commercial product to a surrogate by 2018. The objective of this collaborative project was to conduct studies to systematically from Prowl® 3.3 EC to a Surrogate Test Chemical for ISO 27065 and ISO/DIS 18889.

Transition from Prowl® 3.3 EC to a Surrogate Test Chemical
Figure 1 includes the process used for the development of surrogate test chemicals.

Pesticide penetration study conducted with 65 commercial pesticide products was the basis for selection of representative formulation (FR-EC01) for further testing. This commercial product is representative of the worst case scenario. In addition, the solvent in the EC formulations is in compliance with REACH regulations. Additional tests, including testing of materials sensitive to difference in surface tension of the test chemical, were conducted to validate FR-EC01. The development of the surrogate based on FR-EC01 was a 2-step process. For Step 1, an intermediary step, six mixtures with lower % pendimethalin (5% and 10%) in the concentrates were formulated. Testing with lower % of pendimethalin (a dinitroaniline compound) was to allow replacement of the a.i. with a dye that has similar physio-chemical properties in Step 2.

Step 1: Testing with Non-commercial Mixtures of Pendimethalin

Figure 1. Development of surrogate test chemicals.
Six mixtures prepared for testing were based on EC formulations (Table 1). M1, M2 and M3 had 5% pendimethalin and the other three corresponding 10% mixtures had the same components with % of one or two components higher to make up the difference. Ease of formulation was also considered for the surrogate; the first set (M1,M4) was the simplest with pendimethalin, an emulsifier and a commonly used solvent. The mixtures were diluted with distilled water such that the proportions of the concentrate and water were similar to that of 5% FR-EC01 (15 mL of concentrate was made up to 100 mL). Diluted formulations of mixtures and FR-EC01 were used for penetration and permeation tests and concentrates for permeation testing. In addition, penetration test was conducted with blank (no active ingredient) of each mixture to ensure there was no interference in chemical analysis. Based on test results, four mixtures (M2, M3, M5, M6) had the potential for development of surrogate. The information was sent to ISO/CEN experts and risk assessors to allow an opportunity to review and comment.

**Step 2: Development of a Surrogate with Dye**

Based on physio-chemical properties disperse orange 37 \((3-[4-(2,6-Dichloro-4-nitrophenylazo)-N-ethylanilino]propionitrile)\) and disperse yellow 26 \((4-chloro-2-nitrodiphenylamin)\) were selected for development of surrogate with dye. Of these, disperse orange was rejected because of very low solubility in solvents; EC with the highest concentration of the dye contained only 0.25 g/L of the dye. The solubility of disperse yellow 26 in solvents was acceptable. However, the inert ingredients had to be re-balanced to achieve the desired emulsion properties (see table 1). Three surrogates (M5, M6, Dye surrogate) developed at BASF headquarters was formulated at BASF lab in Brazil for testing. Based on initial tests M6 was selected as the surrogate with pendimethalin (surrogate option 2 if results for dye surrogate were not satisfactory)

<table>
<thead>
<tr>
<th>Code</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>Dye Surrogate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendimethalin/dye</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Agnique ME 18 RD-F</td>
<td>44%</td>
<td>31%</td>
<td>41%</td>
<td>29%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lutensol TO 7</td>
<td>15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soprophor 4D 384</td>
<td>5%</td>
<td></td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
<td>2%</td>
</tr>
<tr>
<td>Soprophor BSU</td>
<td>5%</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wettol EM 31</td>
<td>15%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agnique AMD 12</td>
<td>46%</td>
<td>34%</td>
<td>44%</td>
<td>31%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solvesso 200 ND</td>
<td>90%</td>
<td></td>
<td>85%</td>
<td></td>
<td></td>
<td></td>
<td>45%</td>
</tr>
</tbody>
</table>
Penetration tests with 5% Prowl 3.3 EC, Dye surrogate and pendimethalin surrogate were conducted with Level 1 and 2 fabrics as well as fabric sensitive to surface tension. In addition, permeation tests were conducted with the two materials used for the inter-laboratory trials to compare the existing test chemical with the two surrogates. Based on the results, testing with additional materials was conducted only with Prowl 3.3 EC and dye surrogate. Based on the results, dye surrogate has the potential for replacing Prowl 3.3 EC.

Acknowledgement
Development of the surrogate test chemical was a collaborative project undertaken by the International Consortium for PPE for Pesticide Operators and Re-entry Workers. Special thanks is extended to the following groups within BASF: Formulation Development department for the development of the non-commercial mixtures; OPEX Team for chemical analysis and logistical support for laboratory testing for Step 1; Global stewardship for funds required for development of the surrogates; and BASF Brazil for formulating the surrogates used for tests conducted in Brazil. Testing at Instituto Agronomico, was funded by Fundag. The project was also partially supported through funds received University of Maryland Eastern Shore from National Institute of Food and Agriculture, US Department of Agriculture for NC-170 research project and from European Crop Protection Association and UIPP (French Plant Protection Association) for coordination of consortium activities.

References:
DEVELOPMENT OF CHEMICAL PROTECTIVE CLOTHING EVALUATION DEVICE

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* Corresponding author: Weidong Yu, E-mail: wdyu@dhu.edu.cn

Introduction
In recent years, accidents of hazardous chemicals often occur at home and abroad. In order to reduce the loss of the accident and ensure the safety of the citizens, firefighters in the fire suits must arrive at the scene for the first time. The fire suits are their safety devices at this time. But the casualty rate of the firefighters in the accident has been very high. The existing chemical protective clothing can protect fire safety? The existing chemical protective clothing evaluation apparatus and method is reasonable? It has aroused wide attention of the people.

The current testing methods for permeability performance include the testing methods mentioned in ISO6529, EN369, and ASTM F739. In the three major standards, the basic principles of testing methods for permeability of protective materials are the same. That is to say, the permeability and penetration time are used to evaluate the protective performance of protective fabrics.

The permeation of gases and liquids used in GB23462-2009, ISO6529, EN369 and ASTM F739 is shown in Figure 1.

Most of the existing devices are built on the above standard recommendation. They can only carry out single factor single index test, but in the actual rescue process, rescuers often need to expand under special temperature, pressure and movement state.

Experimental
In the practical application of liquid sealing type chemical protective clothing, rarely dangerous liquid accumulation and residual clothing pose a threat to the wearer of the garment in the case of chemical warfare. Liquid dangerous chemicals are left in the form of folds or cloth joints in the form of droplets. From the microscopic point of view, there will be no corrosion in the absence of infiltration. In theory, when the contact angle between the droplets and the fabric is large enough, the liquid solid is point contact. Thus it can be seen that the larger the contact angle, the infiltration process is more difficult to continue, and the corrosion phenomenon is more difficult to occur.
The temperature control board can control the fabric temperature, the horizontal direction photography system is used to measure the parameters such as fabric contact angle and rolling angle. The vertical direction photography system observes the fiber dissolution, and completes the evaluation of liquid tight chemical protective clothing with the penetration test of adjustable pressure. In the practical application of airtight chemical protective clothing, the wearer often works under different temperature, pressure and movement state. The instrument needs to imitate the actual situation, so the following device is developed.

The unique design makes the insulation test chamber and trap cavity independent temperature control and do not affect each other, the computer to control the stepper motor to change the chamber volume, complete control of chamber pressure and fabric tension, feedback through the built-in camera system, the chamber magnetic stirring apparatus for gas distribution in the chamber.

Results
The existing equipment can not effectively evaluate the protective performance of the fabric, and the development of the in situ measurement device has great practical advantages and great significance.

Acknowledgement
This work was supported by the National Key R&D Program of China (2016YFC0802802).

References:
2. SNV DIN EN 369-1993, Protective Clothing; Protection Against Liquid Chemicals; Test Method: Resistance Of Materials To Permeation By Liquids.

4. GB/T 23462-2009 Protective clothing - Test method for chemical protective materials to permeation by chemicals
USE OF SPECTROPHOTOMETRY UV-VIS IN THE PPE FOR PROTECTION AGAINST PESTICIDES ASSESSMENT

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Introduction
Since the first publication of ISO 27065[1] in 2011, it has been used by the Ministry of Labor and Employment as a law for quality for personal protective clothing for pesticides operators in Brazil. In this standard, ISO 22608 [2] to measure pesticide penetration through fabrics and seams; the revised standard also requires measurement of repellency for Leve 2 fabrics. ISO 22608 has two methods of analyzing the results. As stated in the standard, tests are conducted using method A, the gravimetric method. Method B which requires chemical analysis to quantify the active ingredient, is used only when penetration is within ± 20% of the maximum penetration limit or when method A shows penetration, but the yellow color characteristic of the test chemical is not observed in the collector layer. Method B is often both expensive and time consuming as high pressure liquids chromatography (HPLC) and gas chromatography (GC)) are commonly used for chemical analysis. Since the active ingredient of the test chemical is yellow, spectrophotometric analysis is an option that would make the testing for certification faster and cheaper. This method was used by a laboratory in the inter-laboratory study conducted to compare method A and B. This study builds on the previous study by comparing the same extracts using chromatography and spectrophotometry. The objective of this work was to analyze the possibility of using spectrophotometry in the analysis of the samples obtained through the application of ISO 22608.

Material and Methods
The tests were conducted in the Laboratory of the QUEPIA - Program of Quality for Personal Protection Equipment in Agriculture, located in the Center of Engineering and Automation of the Agronomic Institute (IAC), in Jundiaí – SP, Brazil, during the months of August to November of 2017. To develop the spectrophotometric method, standard solutions containing 0.05, 0.50, 2.50, 5.0, 15, 30, 60 and 120 ppm of pendimethalin were prepared and initially three replicates were analyzed in the wavelength range from 270 to 690 nm, with intervals of 30 nm. After the first results the test was repeated with three replicates in the 400 to 480 nm range, at 10 nm intervals. Wavelength of highest absorbance was identified and a calibration curve was constructed and analyzed with standard solutions.

Two cotton/polyester fabrics that meet the fabric requirements for ISO 27065:2017 after 30 washing in accordance with ISO 6330 method 4N [3] were used for the study. Fabric A met Level C1 requirements and Fabric B Level C1 requirements. Tests were conducted by pipetting 0.2 mL of test chemical (Prowl 3.3 EC®, an emulsifiable concentrate with 37.4 % pendimethalin, diluted with distilled water to 5 % a.i.). Six replicates of each fabric were used for the study. Each test specimen and absorbent paper was extracted in 50 mL of acetonitrile in accordance with ISO 22608 Method B. Extracts for each test specimen and absorbent paper
were analyzed by HPLC and spectrophotometer. The means being compared by the F test and the Tukey test at 5% probability.

**Results**

The range of wavelengths for pendimethalin detection was from 330 to 510 nm with best results at 430 nm. The concentrations range from 0.5 to 120 ppm showed a linear quantification curve (conc = 53,726 abs – 0.183) with a high correlation level ($R^2 = 0.9999$). The Table 1 show the average of results to quantification of pendimethalin in the samples for both fabrics. The mass balance was between 95 and 105% as required by standard and the repellency, retention and penetration was very similar. For all analyzes performed no statistical difference was observed between the readings for the two methods analyzed. By the results, the color is an efficient method to determine the amount of test liquid in the samples.

**Table 1.** Quantification of pendimethalin in fabrics samples by high performance liquid chromatography (HPLC) and spectrophotometry UV-VIS.

<table>
<thead>
<tr>
<th></th>
<th>Fabric A</th>
<th></th>
<th></th>
<th>Fabric B</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HPLC</td>
<td>UV-VIS</td>
<td>HPLC</td>
<td>UV-VIS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (1)</td>
<td>sd</td>
<td>Mean (1)</td>
<td>sd</td>
<td>Mean (1)</td>
<td>sd</td>
<td></td>
</tr>
<tr>
<td>Repelence (ppm)</td>
<td>&lt;LOQ</td>
<td>&lt;LOQ</td>
<td>99.2</td>
<td>1.5</td>
<td>102.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Retention (ppm)</td>
<td>88.8</td>
<td>4.4</td>
<td>91.9</td>
<td>5.2</td>
<td>3.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Penetration (ppm)</td>
<td>13.2</td>
<td>4.9</td>
<td>13.3</td>
<td>5.0</td>
<td>&lt;LOQ</td>
<td>&lt;LOQ</td>
</tr>
<tr>
<td>Sum</td>
<td>102.0</td>
<td>1.2</td>
<td>105.2</td>
<td>1.0</td>
<td>102.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Mass Balance (2)</td>
<td>101.2</td>
<td>1.2</td>
<td>100.0</td>
<td>0.9</td>
<td>101.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Repelence (%)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>96.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Retention (%)</td>
<td>87.1</td>
<td>4.7</td>
<td>87.4</td>
<td>4.7</td>
<td>3.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Penetration (%)</td>
<td>12.9</td>
<td>4.7</td>
<td>12.6</td>
<td>4.7</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

(1) Limit of quantification (LOQ) +. Mean of six replicates

(2) Calculated based on control sample with 100.84 ppm (HPLC) and 105.137 ppm (UV-VIS).

**Conclusions and Plans for Study**

Based on the study, quantification of the results in the ISO 22608, method B, can be performed by UV-VIS spectrophotometry without loss in quality. Studies are planned to validate the method with additional materials as well as to determine if the method is suitable for measuring permeation required for Level C3 in ISO 27065:2017 and ISO/DIS 18889. Moreover, in 2016 decision was made at the ISO meeting to transition from a commercial product as test liquid to a surrogate by 2018. Since both options for surrogates under consideration require analysis of a colored chemical for Method B, spectrophotometry could be considered in the future. Thus, the objective of this study was to compare spectrophotometry also has the potential of being used for quantification of the surrogate. Thus, spectrophotometry has the potential for being used as a method for faster and cheaper, without loss in quality when compared with the quantification by chromatography.

**References:**


CHARACTERIZATION OF THE SURFACE TENSION OF SYNTHETIC BLOOD USED IN ISO 16603 PENETRATION TESTS

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Nacional Institute for Occupational Safety and Health (NIOSH) (US)

Background
The ISO 16603 test method was designed to measure the penetration resistance of clothing materials to a synthetic blood simulant (1). Because surface tension affects liquid penetration, the test method specified the surface tension to be 0.042 N/m. However, urethane based synthetic blood has been shown to have a range of surface tension dependent on time, exposure to atmosphere and testing apparatus (2). The purpose of this research is to measure the surface tension of synthetic blood used in ISO 16603.

Methods
Synthetic blood was formulated according to ISO 16603 (1). Surface tension was measured with three test methods (capillary tube, optical tensiometer, and duNouy ring). Samples were mixed prior to each measurement, but rather than shaking which has been found to change the surface tension, sample containers were inverted and gently swirled (2). Capillary measurements were made with a 0.5 mm capillary tube calibrated according to manufacturer instructions (Catalog No. 14-818, Fisher Scientific, Pittsburgh, PA). Optical measurements were made using a Theta Lite tensiometer and OneAttension software ver. 2.5 (Biolin Scientific, Linthicum Heights, MD). Optical measurements were recorded for 10 minutes. Ring measurements were made with a duNouy precision tensiometer (model 70535, CSC Scientific Company, Inc., Fairfax, VA). Ring measurements were measured in a 90 mm plastic petri dish filled with 35 ml of synthetic blood at 1, 5, 10, 20, 40, and 60 minutes.

Results
The surface tension of synthetic blood measured with the capillary tube method was 0.0485 N/m. Optical tensiometer and ring measurements began at 0.0567 N/m and 0.0492 N/m, respectively. These measurements were still declining and had not reached equilibrium within the sample time allotted (Figure 1). Continued measurements over two weeks using optical tensiometer showed that the surface tension is stable for about three days, declines for 3 days and then increases (Figure 2). These results suggest that the ISO 16603 test method should be amended with specific attention to recommendations on the shelf-life of the cellulose-based synthetic blood. The two batches (A and B) are not the same. Further research is needed to determine effects of factors such as starting water temperature, mixing time, and mixing speed. Further research is needed to determine causal effects such as cellulose hydration and cellulose entrapment of surfactant.
Figure 1. The surface tension of ISO 16603 synthetic blood measured by capillary tube, duNouy ring and optical tensiometer.

Figure 2. The surface tension of ISO 16603 synthetic blood measured by optical tensiometer at 120 seconds after drop formation by day (experiment repeated: “Batch A” and “Batch B”).

Key Words: Synthetic Blood, ISO 16603, Surface Tension, Penetration, Test Methods

References:
PROTECTION AGAINST HOT STEAM INJURIES: HOW DOES STEAM PENETRATE THE HUMAN SKIN?

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When fighting fires, firefighters are exposed to a hot and humid atmosphere. High amounts of moisture are either generated from the vaporization of extinguishing water or from the evaporation of the sweat produced by the firefighters themselves [1]. However, the mechanisms leading to skin burn injuries due to the hot steam exposures are not well understood. The goal of this study was to analyze the transfer of hot steam through the skin by using porcine skin as ex vivo model. We exposed different skin samples to either dry heat or hot steam and the changes in skin hydration were measured using Raman confocal microspectroscopy.

The skin is composed of two principal layers: the epidermis and the dermis. The outermost layer of the epidermis, the stratum corneum (SC) consists of dead cells and is the primary protective layer against thermal and mechanical stressors. However, the epidermis and the stratum corneum are not fully impermeable layers. The SC contains pores of around 0.4 to 100 nm (typically of the order of 10 nm), which are larger than the size of water molecules (0.3 nm). There are three different pathways for water molecules to penetrate the skin: intercellular and transcellular pathways as well as through the appendages.

Our study showed that during the first seconds of steam exposure, the water content of both the epidermis and the dermis increased. This can be explained by the intercellular pathway: water molecules penetrate the voids between the cells of the SC and condensate in deeper tissue. Part of the steam was absorbed by the SC through transcellular pathway which led to a swelling of the cells. This reduced the intercellular pathway and after 15 seconds of exposure, there was no significant water uptake in the deeper layers. However, the water molecule penetration in the epidermis and the dermis during the first 15 seconds of exposure leads to water condensation in deep skin tissues with a considerable release of heat. This study shows for the first time why hot steam skin burns may be more severe than dry heat injuries.

Keywords: firefighters, thermal protection, hot steam exposure, skin burn injuries.

References:
A SOFTWARE FOR BODY INJURY ASSESSMENT AND PERFORMANCE EVALUATION OF PERSONAL PROTECTIVE CLOTHING

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Abstract

Firefighters and other emergency rescuers are exposed to complex hazards, including fire smoke, hot/cold environment, explosion or toxic chemicals, et al. In order to assess the potential injury for better protection, it is necessary to conduct an analysis that quantify simultaneously the human physiological responses and the performance of personal protective clothing (PPC) under the multi-hazard environments.

Therefore, an online software tool is presented here for the integrated evaluation of the body injury and individual protection, by using the models of thermal physiological response and multi-layer clothing. Different sizes of Computer Simulated Person (CSP) with a respiratory tract are developed from 3D Scanning of male and female volunteers. A multi-segment thermophysiological model (Yang et al., 2017) is coupled with Computational Fluid Dynamics (CFD) (Fu et al., 2016), to simulate the thermal responses under various environmental conditions. Moreover, the injury models of thermal burn in the human skin (Fu et al., 2014, 2015) and respiratory tract (Xu et al., 2017), dermal exposure to chemicals, and trunk damage after blast wave are also considered herein. The protection and ergonomic of PPC is also assessed for fire extinguishing and emergency rescue, disposal of hazardous chemicals, stab-cut and explosion shock. The present software can provide a convenient tool for us to estimate human body injuries and individual protection efficacy to finally help with the PPC development.
Figure 1. Schematic diagram of the integrated analysis software.

Figure 2. Software interface of the online assessment tool for body injury and performance efficacy of PPC.

Acknowledgement
This study was supported by National Natural Science Foundation of China (Grant No. 51706123), National Key R&D Program of China (Grant No. 2016YFC0802801 and 2016YFC0802807), National Science Fund for Distinguished Young Scholars of China (Grant No. 71725006), and the Open Foundation of Hefei Institute for Public Safety Research, Tsinghua University. The authors are deeply grateful to these supports.

References:


A KIND OF THERMAL BARRIER WITH INTELLIGENT ADJUSTMENT THICKNESS

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*Corresponding author: Weidong Yu, E-mail: wdyu@dhu.edu.cn

Introduction
The dangerous moment of fire exists in our side. Whether it is a natural forest fire or the burning of a building, it will bring social or personal losses. Protective clothing for firefighting is the only barrier that firefighters block the fire, firefighters needed a protective clothing for firefighting that would ensure he had 30 to 120s to safely evacuate the fire. However, the thermal protection performance of domestic protective clothing for firefighting is generally low. Therefore, it is very necessary to develop protective clothing for firefighting with high efficiency thermal protective performance.

Experimental
In this paper, the thermal protection performance of protective clothing for firefighting is improved by designing a kind of thermal barrier with intelligent adjustment thickness. Air gap will affect the thermal protective performance of the protective clothing for firefighting(1). The thermal barrier can thicken intelligently when encountering high temperature and increase the thickness of the air inside the protective clothing for firefighting so as to improve the thermal protective performance and restore the original shape at normal temperature, thus having the function of shape memory. The thermal barrier is an ingenious combination of high performance fiber, yarn, tissue and weaving method. This shape memory thermal barrier not only realized the intelligent thickening of the protective clothing for firefighting, at the same time realized the weight loss. It can be used for high temperature environment for fire fighting, volcanic exploration, geological exploration, etc. The thermal barrier with intelligent adjustment thickness has been woven out. Two kinds of samples are shown below.

Figure 1. Two kinds of samples.
Results
Shape memory thermal barrier with flame retardant layer, moisture barrier and comfortable layer compound, formed protective clothing for firefighting. Test the thermal protective performance of protective clothing for firefighting, verify the protective clothing for firefighting with shape memory thermal barrier really can significantly improve the thermal protective performance. It is proved that the thermal protective performance of protective clothing for firefighting is improved significantly when using shape memory thermal barrier. The shape memory thermal barrier can be used in fire fighting condition, volcano, geological survey, exploration protective equipment fabrics and their preparation.

Acknowledgement
This work was supported by the National Key R&D Program of China (2016YFC0802802).

References:
DEVELOPMENT OF SENSORIZED PROTECTIVE PERSONAL EQUIPMENT FOR HAZARDOUS ENVIRONMENT AND OPERATIVE PERSONNEL ASSESSMENT

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Development of continuously monitored conditions and user/worker based monitoring and self-assessment systems in hazardous outdoor and indoor environments has been the focus of several R&D projects in recent year by integrating wearable wireless communication technologies into and onto textile garments and clothing, personal protective equipment (PPE), machinery and other user-centered wearables and objects. The concept of interconnecting all of the sensing structures in data collection interoperable platforms has allowed for the development of internet of things concepts and solutions for textile and polymer based PPE that enable sensing and monitorization of hazardous environments.

In this work we present the development of “self-assessed” and sensing devices printed directly onto textile substrates, or integrated onto polymeric PPEs. The pilot test environment consisted of a domestic and industrial waste management and co-incineration facility in the North of Portugal, targeting the integration of continuous monitoring (and self-assessment) of the environmental conditions and physical data of workers (e.g. position) assigned to handle hazardous waste recycling during separation processes. The overall environmental monitoring and management of the plant and its workers will be assured by the installation of a closed system online platform database.

The development of printed and flexible electronic nose gas sensors for specific analytes allowed the development of new integration processes using textile substrates, using also the combination with conductive yarn integration in order to develop a complete textile integration of the sensors. The printed e-nose devices and gas sensors were processed using a combination of R2R PVD and wet coating/printing technologies using textile substrates or polymeric substrates for subsequent integration onto injection molded PPEs or other textile multilayer membranes (for encapsulation). Additional flexible textile sensors were integrated directly onto the PPE clothing to enable biomonitoring and indoor GPS tracking of workers in placed in hazardous conditions. The e-nose sensors were calibrated to monitor concentration of oxygen and methane for regular atmospheric conditions. Additionally, textile and polymeric/plastic were also integrated with temperature, relative humidity and real-time positioning sensors. Individual data communication platforms, for data management, were used and identified to integrate Bluetooth 5, low energy, communication modules.
SENSOR-BASED WEARABLE AIRBAG SYSTEMS FOR VARIOUS FALL SCENARIOS

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According to the German Social Accident Insurance in 2012 a number of 26,828 accidents have been reported at German working sites due to fall from height. Roughly 21% of the resulting injuries were inflicted to neck, hip and the spinal column. The resulting compensation costs are estimated to 1.5 billion € [1]. Especially for heights reaching from 1 to 5 metres currently available protection systems on the market cannot guarantee safety. This deficit in the state of the art was the motivation for the development of a sensor-based airbag which shall prevent critical fall damage, by means of a special one-piece woven airbag design [2]. Within the basic research project the authors could prove the protection effect up to falling heights of 4.5 metres, with an obtained Head Injury Criterion (HIC) below the critical limit of 1000.

An airbag system integrated inside a vest is currently prepared for market entry [3]. Present speech aims at introducing further possibilities for a use of the developed sensor-based airbag systems. The roadmap of the technology transfer of the sensor-based airbag systems into further fields of application as intended by the inventors and manufacturers Minerva-AS GmbH is shown in Figure 1. Targeted sectors are occupational safety, sports and home applications. The challenges in development and certification processes will be discussed. As in every field of application fall movements are significantly diverse, sensor systems, inflating units, the respective algorithms and textile structures always have to maintain a very specific set of characteristics. Hence for every field of application there shall be a specific airbag system. The approaches and methods applied for the development of the specialised airbag systems are presented and discussed.
Acknowledgement
The project “ScaffBag” was funded by the German Federal Ministry of Economics and Energy within the framework of the “Zentrales Innovationsprogramm Mittelstand (ZIM)”.

Keywords: quality, process, automatic, smart factory.

References:
WESENSS: WEARABLE WIRELESS DEVICES FOR VITALS AND BODY-AREA ENVIRONMENT MONITORING OF FIREFIGHTERS

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Introduction

Firefighters (FFs) are considered a high-risk occupational group that is constantly exposed to severe stress and fatigue, with a negative impact on their health and performance [1]. There is an urgent need to intervene with these professionals in order to support and help them to perform in the best of their abilities and consequently increase the overall safety. FFs decisions are mostly dependent on the information provided by their own senses and experience when deciding where and how to approach a critical event. It would be easier in these situations to have a system capable of providing better real-time support and help in the decision-making process. WeSENSS is a wearable platform resulting from the VitalResponder® line of research projects with the aim to design new technologies to help FFs to improve their effectiveness in operations and increase their safety.

Wearable Devices for Safety

The WeSENSS platform allows monitoring of body-area environment and several inner physiology variables to quantify FFs exposure to different work conditions and infer their stress and fatigue levels, introducing the concept of a quantified Occupational Health (qOHealth) platform for FFs. Hence, two different body-area wearable devices were developed: one to collect vital signs and the other to gather the professional’s environment surroundings variables. The vital signal wearable device is being developed in cooperation with Biodevices, S.A., a wearable medical devices company that develops technology in the textile embedded electronics area. An example of their products is the VitalJacket® t-shirt [2, 3], a wearable device with medical certification (MDD- 93/42/EEC), capable to acquire medical quality multi-lead ECG and actigraphy data in ambulatory scenarios, transmitting all the data through Bluetooth. Initially we tested the VitalJacket® commercial version for FFs usage, determined additional requirements and further developed an extension of the VitalJacket® smart t-shirt specifically designed for hazardous professional, with a body temperature sensor and a more breathable textile with a higher burning temperature to tolerate higher surroundings’ temperature. This improved model was used in real fire scenarios for 2 years with remarkable success. While the new smart t-shirt is being deployed in real operations, we have further developed this concept following our “macro-to-micro” advanced human sensing line of research, and further reduced our device size, transforming it into a skin patch form-factor, making the device even more user-friendly. This new prototype, named VitalSticker, is a patent pending technology [4] with medical grade quality ECG, highly robust to motion artifacts (major problem in skin surface devices) using only two electrodes.

For the ambiance monitoring, a device capable to monitor several ambiance variables, named AmbiUnit was developed. The AmbiUnit is capable to acquire environmental temperature,
humidity, atmospheric pressure, luminosity, relative altitude, carbon monoxide, nitrogen dioxide and air particles concentrations. Both toxic gases and air particles are of major importance because they can influence health in short and long terms. This device can be worn in the belt or in the helmet of FFs, sending all the data through Bluetooth.

The data from both of these body-area devices are gathered in a smartphone app with the geolocation of each individual, storing all the data and sending them wirelessly to a command center, being available in a live platform. This allows the chief mission commanders to access the data and location of each individual in real-time helping them to better manage the team and improve their decision-making process. Both platform and individual app can have alarms to help FFs to better perform and surveille their own health.

Besides the variables acquired from the devices, some tools are being developed to assess stress and fatigue among FFs in real-time. VJAssembly is an offline platform where several physiological parameters related to heart rate variability (HRV) could be computed and tested. Most of these algorithms are already implemented in the online mode.

Results

Several studies were conducted with FFs in order to test this system [5,6]. As an example, a controlled fire drill was conducted with 4 FFs in order to understand psychophysiological stress changes on FFs. A total of 23 hours of clinical grade ECG, body temperature and actigraphy were collected. The analysis showed different changes in physiological behavior, particularly an increase in body temperature and a decrease in pNN20 (stress indicator) during events, suggesting an increase in cardiac strain and stress. More studies should be conducted considering that the understanding of psychophysiological stress changes on FFs would help on the design of controlled and more realistic emergency training scenarios.

Acknowledgments

This work has been financed by National Funds through the FCT - Fundação para a Ciência e Tecnologia (Portuguese Foundation for Science and Technology) within the project “VR2Market” grant CMUP-ERI/FIA/0031/2013 and project NanoSTIMA funded through the North Portugal Regional Operational Program (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF). The authors would like to thanks all the previous and current members of the project team that involves also firefighters from Albergaria-a-Velha and Vila Real-Cruz Verde, consultants and researchers.

Keywords: stress; firefighters; VitalSticker; VitalJacket®; AmbiUnit; VJAsembly.

References:

4. INESC TEC, 2016, Medical Device with Rotational Flexible Electrodes, Portugal, 20161000064607, filed 25 August 2016, Patent Pending
SMART PPE STANDARDIZATION ISSUES

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Introduction
Due to the technical progress verified in the recent years, textile materials and electronic components are nowadays combined to develop new personal protective equipment (PPE) with enhanced features. Along with these developments, there is the constant need for adequate standardization. The increasing needs of PPE users, like protection against the extremely dangerous situations in the working environment, as well as their expectations driven by the technical progress, led to the appearance of a cross cutting field of smart PPE garments and textiles. This new group of PPE, commonly called smart or intelligent PPE, cooperates with the human body and reacts to changes in the external environment in a controlled and programmed way [1]. Some of them, with permanently integrated electrical circuits or parts of electrical circuits, are called electronic textiles (e-textiles). Concerning textile wearable technologies, three groups may be defined: (1) wearable devices where a sensor is attached to an apparel; (2) sensors embedded in the garment; (3) the garment is the sensor (next generation of wearable textiles). The latter will accomplish the user’s need of shape, stretch and washing. Although the integration of both components is a reality nowadays, these two areas of expertise (textiles and electronics) are commonly seen as distinct areas [2].
The impact on bringing smart PPE products onto the EU market: Standardization issues
The manufacturer has the responsibility to sell a safe product, so compliance with EU legislation, type of product and the intended use, components and end-of-use (textiles, electronic components, materials/hazardous substances, recycling, disposal) is mandatory. Attention to the risks, hazards, reliability and responsibilities is also very important. Nevertheless, it is very difficult for the suppliers to bring new and compliant products to the market without standards identifying and describing the performance requirements and test methods.
The overview of the needs for standardization related to the PPE was prepared by CEN-CENELEC BT Working Group 8 in 2014, following a programming mandate (M/509) issued by the EU Commission as one result of the lead market initiative on protective textiles [3]. In 2016, the EU Commission has drafted a standardization request, to CEN, CENELEC and ETSI, the European standardization organisations (ESO), for identifying and describing the performance and properties of ‘Garments and ensembles of garments, with integrated smart textiles and non-textile elements that provide protection against heat and flame’. Moreover, the new standards shall take into account and not duplicate already existing relevant European and International standards in the field of protection against heat and flame (M/553) [4].
Looking deeply into e-textiles (electronics and textiles), when it comes to testing e-textiles for performance and safety, it is important to think about standards and test methods for textiles, for electronics and also the whole garment (we must test the garment system). Of course, standards and test methods already exist at component level (textile, electronics) but e-textile
testing still is a challenge. Some testing issues regarding textiles and electronics should be analysed together. In the case of textile materials, test methods for launderability (strongly connected to the technologies of integration used), comfort (stretchability, hand, fit), durability (abrasion, aging, UV exposure) and end-of-life sustainability should be applicable to the product ensemble (textile and electronic components). The same for some electronic test methods (water proofing, electrical shocks, maintaining circuits, overcharging power source, effect of vibration and mechanical shock, resistance to heat and flame, among others), which should be addressed taking into account the whole product [2].

Some organizations: CEN TC248 Textiles and textile products, WG31 Smart Textiles – 2008 (Europe); IEC TC124 Wearable Electronic Devices and Technologies (continuing the work of IEC SG10) – 2017; ASTM Subcommittee Smart Textiles (D13.50) – 2016; AATCC R111 Electronically Integrated Textiles – 2016, are already working on the standardization of smart textiles and wearable devices. Standards defining terminology (common terminology improves understanding among stakeholders), interoperability of products, product performance, safety and innocuousness (testing and evaluation, compliance with European legislation, end-of-life, recycling, reuse, safe disposal) are needed. More than the development of new standards, the big challenge in this field is to gather electronics and textile players, developing new interactions between the textile and microelectronics industries and organizations to help define and shape the new e-textile testing playing field and rules of the game, because of the many ways e-textiles can be produced [2].

Conclusions
The continuous growth of textile and clothing industries, together with the improvements observed in electronics, has led to the development of smart PPE. This area is a continuously growing market, due to the comfort and important extra functions these systems provide to PPE users. Even though this is a growing area, some important challenges should be overcome, namely standardisation, correct maintenance, the security and privacy of user data and innovative business models that can capture the full value of such smart systems. Requirements for testing and verifying properties, criteria for classifying performance according to test results, and for informing about attributes and functionalities; test methods for the determination and evaluation of performance; and guidance for selection, use, care and maintenance, are expected to be available in a near future.

Acknowledgment
The author gratefully acknowledge Henk Vanhoutte, chair of CEN-CENELEC BT WG8 and Karin Eufinger, convener of CEN TC248 WG31.

Keywords: Smart PPE; e-Textiles; Smart textiles; Test methods; Standardization; User’s needs.

References:
[4] CEN-CENELEC report on a standardisation request to the European standardisation organisations as regards advanced garments and ensembles of garments that provide protection against heat and flame, with integrated smart textiles and non-textile elements for enhanced health, safety and survival capabilities.
MEASURING MOISTURE EFFECTS ON CLOTHING THERMAL PROPERTIES IN THE COLD WORK: HUMAN AND THERMAL MANIKIN STUDY

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Introduction
Workers in Arctic open-pit mines are exposed to harsh environmental conditions in winter that requires protection against cold and wind. Work intensity often fluctuates between light and heavy work or workers have to move between cold and warm spaces which may cause moisture accumulation into clothing due to sweating. The moisture transport through clothing consists of several complex mechanisms, and it is influenced by ambient temperature and clothing materials (1). This study aimed to determine sweating and its effects on open-pit miners’ cold protective clothing during outdoor work. Moreover, it was aim to compare two sweating methods using thermal manikin to simulate human sweating comparable to actual working conditions.

Experimental
A human study (n=14) was carried out in the two open-pit mines in Northern Finland and Sweden while working outdoors during a typical work shift. Ambient (Ta) and skin temperatures (Tsk), dry heat loss from the skin and relative moisture inside the clothing were measured. Air humidity was measured by humidity sensors between under and mid-layers at two body sites (chest and upper back), and moisture accumulations in the clothing by weighting garments before and after work shifts. Subjective evaluation of thermal sensation, comfort and skin wettedness were asked. In the laboratory, moisture effects on the open-pit miners’ cold protective clothing properties were measured. Two sweating methods and manikins were used and compared in non-isothermal conditions (Tmanikin≠Ta) at ambient temperature of -10°C: 1) pre-wetted skin method, and 2) permeable skin method (1). In pre-wetted skin method 300g of water was saturated into an inner clothing layer and a sweating rate in the permeable skin method was 100 g/m²h during 2 hours. This moisture input inside the ensembles corresponds with perspiration in light or medium level physical activity.

Results
The field study showed that almost 75% of the workers expressed that their clothing felt at least “slightly wet” due to sweating. Moisture accumulation averaged 26g (±11g, SE) in outdoor workers’ under and mid-layers after work shift. A maximum accumulated moisture after the shift was 151g, which corresponds with sweating rate during one hour heavy exercise. Relative and absolute humidity underneath the clothing fluctuated along the work shift, but humidity seemed to be evaporated during long breaks when jacket was removed. The laboratory simulation by two sweating methods showed that the permeable skin method created lower moisture content (220g) in the clothing after sweating period than pre-wetted skin method. The manikins differed, except in sweating methods, also in configuration and size. The pre-wetted skin method can be used to evaluate moisture effects on clothing thermal properties. However, it cannot be used to simulate the actual dynamic working conditions similarly than the
permeable skin method. The presentation will explore in more detail the correlation between human and thermal manikin methods.

Acknowledgement
This study was carried out as part of the project “MineHealth - Sustainability of miner's well-being, health and work ability in the Barents region “, which was financially supported by the European Union, Kolarctic ENPI.

References:
BACKGROUND

Fabrics used in firefighters’ clothing provide thermal protection from heat and flames according to the fabric properties. In addition, the trapped air underneath these fabrics significantly contributes to the protection as it provides high additional thermal insulation. The thickness of the air layer depends on several factors such as garment design, fit of a garment and body region. Previous studies in different labs showed correlation between air gaps assessed with 3D scans and predicted burn risk [1-3]. Furthermore, benchmark studies have been conducted on protective properties of fabrics and air gaps [4, 5]. The aim of this study is to get more in-depth knowledge about air gap distribution on protective clothing systems and predict protective properties such as transferred energy and burn risks in firefighter jackets related to air gap thickness. The research done at Empa regarding air gap distribution and contact area and its influence on thermal insulation and comfort has been applied to firefighting clothing assemblies tested under simulated flash fire conditions according to ISO 13506.

MATERIALS AND METHODS

A firefighter jacket has been adjusted to represent the same average fit (ease allowance) at manikin used for scanning and the flame manikin. Four repetitions of 3D scanning and post-processing have been carried out according to a standard operation procedure developed in-house to obtain a detailed distribution of air layer thickness at individual body regions [6]. Transferred energy and predicted burn risk of the same garment when exposed to a simulated flash fire according to ISO 13506 [7, 8] were correlated to the air gaps assessed by 3D scanning. Accuracy of scanning was better than 1.65 mm for 95% of the assessed surface area [6]. Comparison was done on 10 body segments of the upper body (upper and lower arm, upper and lower chest, abdomen, anterior and posterior pelvis, upper and lower back, and lumbus).

RESULTS AND DISCUSSION

Figure 1 shows the 3D scan, air gap distribution and corresponding burn risk in a firefighter turnout jacket. Average burn risk and transferred energy showed clear correlation to the average air gap thickness in the investigated body regions (Figure 2). Correlation was highest for transferred energy. Excluding the back of the manikin 81% of the transferred energy can be explained by the air gaps in the clothing system (63% of 2nd degree burn risk) as shown in figure 2. Back of the upper body of the manikin showed a higher variability in burn risk due to flames sometimes going underneath the garment and Velcro attachments in the upper back area which resulted in after burn.
Conclusion
The results of this ongoing study show that it is possible to predict burn risk for firefighter turnout gear based on air gap distribution. Combining this new results with knowledge about changes in air gaps with different body postures [9] the prediction of transferred energy and burn risks for flashover situation in various and more realistic postures will be possible.

Acknowledgement
The authors like to acknowledge DuPont for providing the garments and funding.

Keywords: firefighters’ clothing, thermal protection, burn risk, air gap, contact area.

References:


OFFSHORE WORK IN THE BARENTS SEA

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Introduction
Petroleum industry is moving further North and offshore work in the Barents Sea may cause severe cold problems due to the harsh, rough weather. The purpose of this study was to identify the challenges and differences related to work environment risk for offshore work in the Barents Sea versus work elsewhere on the Norwegian continental shelf. This applies only to some selected occupational health and safety conditions such as physical and mental performance when working outdoors, sleep problems, ergonomic and psychosocial factors as well as some organizational conditions for work on cold climate installations. The results from impairment due to cold weather work and protective clothing will be presented.

Experimental
A questionnaire survey was carried out autumn 2016 in the Norwegian petroleum sector. Those with experience from work in the Barents Sea during the last five years was included in the survey. Total 1,949 responses, of which 349 (18%) with experience from the Barents Sea.

Results
74 % of the respondents have experience from outdoor work in the Barents Sea. 51 % of these felt that the functioning is reduced because of working outdoors in the cold. The highest number reporting that cold hands (98%) and cold feet (55%) is the main problem. Only 5 % feel that the "protective equipment" is not functioning as it should. However, it was not quite clear to the respondent what was meant by protective equipment, it was uncertain whether they included gloves and shoes as part of the protective equipment. 12 % experience that outdoor areas are not adapted to weather conditions, while 15 % experience that they do not have enough time and capacity to roll between indoor and outdoor work. 24 % experience that they do not have adequate training to handle cold exposure and 30 % experience that management does not actively engage in cold problems. Very few are dissatisfied with the amount of work they get done in the cold, but there is potential for improvements in several of the mapped areas (24 %). There are some people that do not experience adequate training in cold exposure (24 percent) and think that the management does not actively engage in cold problems (30 percent). 70 % of the respondents with experience from the Barents Sea and other marine areas find that work on installations in the Barents Sea does not differ from work on installations in other marine areas, while those who think there are differences (14 per cent) typically think that it is some greater risk in the Barents Sea. The other 16 per cent with experience from several sea areas on the Norwegian continental shelf say they do not know if the risk is higher there or not.

Conclusion
The results from this questionnaire demonstrate that cold hands and feet are the main problem amongst offshore workers in the Barents Sea. Only 5 % feel that the protective equipment is not functioning as it should. 14 percent of the workers with experience from both Barents Sea and the Continental Shelf feels think that there is some greater risk working in the Barents Sea. Financed by the Norwegian Petroleum Authorities and the Norwegian Research Council.
MEASURING GARMENT SPATIAL SWEAT ABSORPTION: GRAVIMETRIC AND INFRARED APPROACH

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Introduction
Understanding sweat and moisture absorption in personal protective clothing (PPC) is important for a number of reasons. Moisture accumulation can affect the ability of PPC to protect against prolonged exposure to heat (Barker et al. 2006), influences the acceptance and usage frequency of the PPC by the worker, and will affect the workers performance and productivity through its impact on various aspects of discomfort (Raccuglia et al. 2016, 2017). Building on our laboratory’s work on mapping sweat production distribution across the body (Havenith et al. 2008, Smith et al. 2011, 2012), the aim of the present study was to obtain detailed spatial maps showing how this sweat migrates into the clothing during physical work in a single clothing layer. Currently, the only direct method available to quantify local garment sweat absorption and distribution is a ‘destructive’ gravimetric method developed in the current study. Therefore, a secondary aim was to apply infrared thermography to assess whether it could be used as indirect method to estimate local garment sweat content distribution, in a ‘non-destructive’ fashion.

Method
Sweat production was induced in 8 male participants, during running exercise in warm environment (27 °C, 50 %, 1.5 m·s⁻¹ wind speed). Sweat absorption was mapped across a short sleeved, 100% cotton upper garment, at 5-min intervals over a total running time of 50-min. As a ‘destructive’ gravimetric method was adopted to quantify regional sweat absorption, each participant performed (on separate days) 10 running trials, characterised by different durations: 5 MIN, 10 MIN, 15 MIN, 20 MIN, 25 MIN, 30 MIN, 35 MIN, 40 MIN, 45 MIN and 50 MIN. Immediately after each running trial, the garment was dissected into 22 different parts, 12 for the front and 11 for the back. Analyses of local sweat absorption were conducted at the end of each run duration, by cutting up the marked garment regions and weighing the individual sections before and after drying. Additionally, infrared pictures of front and back of the wet garment (fitted on a T-Shirt-like shape stand) were taken to assess whether the temperature patterns at different garment zones (local garment temperature drop from environmental temperature) were related to the gravimetric sweat absorption data (local garment sweat absorbed in grams). Whole body sweat production, heart rate (HR) and core temperature (Tcore) of the participants were measured.

Results
After 50-min, Tcore rose from 37 ± 0.2 °C to 38.6 ± 0.3 °C, HR increased from 69 ± 15 bpm to 163 ± 12 bpm (p < 0.001) and body sweat production was 586 ± 86 g·m⁻². At 50-min, garment total sweat absorption was 126 ± 57 g·m⁻². Medial mid-back and medial lower-back
were the most saturated garment parts: 56% and 51%, respectively. These were followed by upper back, collar and chest medial (40-45%), and next to these, lateral mid-back, lateral chest and lateral abdomen reached between 30 and 39% of the saturation. Shoulders, sleeves front and back and lateral lower-back were 20-29% saturated and the lowest saturation level was shown by front and back low hems together with lateral abdomen (7-12%). Although visual similarities were observed between the mean infrared (temperature) and the mean gravimetric (grams of sweat) maps, the liner relation between infrared and gravimetric data was not very strong ($r^2 = 0.3$), despite showing significance ($p < 0.001$).

**Conclusions**

A clear pattern of sweat absorption reduction from the top to the bottom and from the centre to the sides of the garment was observed, both for front and back sides. The inter-regional differences in garment sweat accumulation can be explained by the interactions of physiological (sweat production), anatomical (curvature of the body) and clothing (fit, contact) factors. Knowledge of garment regional absorption data can support the development of PPC’s base layers, to effectively manage moisture absorption and drying properties, with the end goal to prevent workers heat-related injuries and reducing discomfort. Furthermore, these data can support the creation of evidence-based textile test methods as well as influence clothing design, e.g. with spatial variation of textile types.

The relation between local garment temperature drop and sweat content in grams, while showing a correlation at low absorption levels, levels off at around 30% garment saturation, where temperature does not drop further with increasing moisture content. Therefore, whilst infrared thermography can be applied as qualitative method to visually detect moisture distribution in a single garment, it cannot be used to make quantitative accurate estimation of regional garment sweat content when saturation levels are high.

**Key words:** Garment wetness, garment sweat saturation, garment sweat maps, PPC design

**References:**

DEVELOPMENT OF A STANDARD PROCEDURE FOR CALIBRATING AN ADAPTIVE MANIKIN

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Introduction
Adaptive manikins, i.e., sweating thermal manikins that mimic human thermo-physiological responses, are used in a wide range of applications. Adaptive manikin control strategies use a human thermoregulation model to predict the body’s thermal and sweating states, which are subsequently used to set the heater control and water flow set-points on a manikin [1]. Example applications include the evaluation of clothing systems [2], EO/IR (electro-optical/infrared) analysis of soldier vulnerability [3], determination of PCS effectiveness [4], evaluation of automotive HVAC systems [5], and assessment of PPE thermal burden [6]. Although calibration procedures exist for sweating thermal manikins operating in temperature set-point control mode [7][8], an established test procedure does not yet exist for verifying the operation of an adaptive manikin. This paper describes the development of a generalized adaptive manikin calibration procedure.

Methods
An effective test protocol should exercise the full range of physiological responses, i.e., shivering, sweating, vasodilatation, and vasoconstriction, as well as thermal states as indicated by the body core (rectal) temperature. To avoid prohibitively long tests, a protocol was developed to maximize the difference in (quasi-static) core temperature while minimizing the test duration. To conform to the ASTM standard manikin calibration procedure [7], which specifies clothing and ambient conditions, hypothermic and hyperthermic states were induced by specifying low MET and high MET activity levels in a relatively cool climate chamber. The test protocol was optimized by simulating candidate scenarios with the TAITherm Human Thermal Module (ThermoAnalytics). Local clothing properties were measured by the same manikin that was used to validate the test procedure (Table 1).
Table 1. Local clothing properties derived from measurements of the ASTM standard clothing ensemble[7] using a Newton manikin (Thermetrics, LLC).

<table>
<thead>
<tr>
<th>Manikin Zones</th>
<th>$R_{cl}$ (m$^2$-K/W)</th>
<th>$R_{e,cl}$ (m$^2$-kPa/W)</th>
<th>$f_{cl}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face (uncovered)</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Head (uncovered)</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Upper Arm Front</td>
<td>0.198</td>
<td>0.030</td>
<td>1.25</td>
</tr>
<tr>
<td>Upper Arm Back</td>
<td>0.146</td>
<td>0.017</td>
<td>1.25</td>
</tr>
<tr>
<td>Forearm Front</td>
<td>0.129</td>
<td>0.017</td>
<td>1.25</td>
</tr>
<tr>
<td>Forearm Back</td>
<td>0.115</td>
<td>0.013</td>
<td>1.25</td>
</tr>
<tr>
<td>Hands (uncovered)</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Upper Chest</td>
<td>0.141</td>
<td>0.012</td>
<td>1.25</td>
</tr>
<tr>
<td>Shoulders</td>
<td>0.154</td>
<td>0.020</td>
<td>1.25</td>
</tr>
<tr>
<td>Stomach</td>
<td>0.290</td>
<td>0.041</td>
<td>1.25</td>
</tr>
<tr>
<td>Mid Back</td>
<td>0.296</td>
<td>0.071</td>
<td>1.25</td>
</tr>
<tr>
<td>Waist</td>
<td>0.343</td>
<td>0.053</td>
<td>1.25</td>
</tr>
<tr>
<td>Lower Back</td>
<td>0.271</td>
<td>0.035</td>
<td>1.25</td>
</tr>
<tr>
<td>Upper Thigh Front</td>
<td>0.431</td>
<td>0.052</td>
<td>1.25</td>
</tr>
<tr>
<td>Upper Thigh Back</td>
<td>0.491</td>
<td>0.070</td>
<td>1.25</td>
</tr>
<tr>
<td>Lower Thigh Front</td>
<td>0.132</td>
<td>0.021</td>
<td>1.25</td>
</tr>
<tr>
<td>Lower Thigh Back</td>
<td>0.163</td>
<td>0.024</td>
<td>1.25</td>
</tr>
<tr>
<td>Calf Front</td>
<td>0.138</td>
<td>0.022</td>
<td>1.25</td>
</tr>
<tr>
<td>Calf Back</td>
<td>0.113</td>
<td>0.015</td>
<td>1.25</td>
</tr>
<tr>
<td>Feet</td>
<td>0.167</td>
<td>0.032</td>
<td>1.25</td>
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</tbody>
</table>

Results and Discussion

Computer simulations indicated that the test protocol should prescribe a 1 MET to 3.5 MET transition in an 18 °C environment. A 4-hour duration for each activity level was chosen to attain (nearly) steady thermophysiological states. The test protocol resulted in vasoconstriction, as indicated by skin blood flow (SKBF=0.1 L/min), and minor shivering (35 W) by the end of the first stage, resulting in a core temperature of 36.3 °C. This was followed by a period of slight vasodilatation (SKBF=0.4 L/min) and sweating (9 g/min), resulting in a final core temperature of 38.0 °C. The Newton/ManikinPC adaptive manikin system (Thermetrics, LLC) was exercised using the same test protocol. The difference between the adaptive manikin’s predicted rectal temperature and the computer simulation was approximately 0.1 °C or less, as shown in Figure 1.

Figure 1. Rectal temperature “measured” by an adaptive manikin (Newton/ManikinPC) compared to that predicted from a computer simulation (TAITherm).
Conclusions

This study demonstrates a methodology for developing a standard test procedure for an adaptive manikin that can be generalized to other manikins and physiological control algorithms. Although the test design considered many aspects common to human subject test design (e.g., by ensuring that the predicted core temperature would not exceed a 2 °C rise or drop from the starting condition), it was not expected that the physiological results would be reproducible in human subjects. Manikins, which would remain still during the high activity exposure period, would lack the augmented convection and evaporative cooling rates caused by realistic body movement. Realism was not a primary objective of this calibration test procedure design since the desired result was to provide a benchmark for manikin operators to ensure that a manikin’s physiological control system is working properly.

References:

DEVELOPMENT AND EVALUATION OF FIREFIGHTING VEST WITH BOTH COOLING AND DRINKING FUNCTIONS TO ALLEVIATE HEAT STRAIN IN SUMMER

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Introduction
Human resource supply system and revision of work-rest schedule are ways to alleviate the heat strain of workers in hot environments. Heat strain can also be alleviated by proper hydration and improvements in personal protective equipment (PPE). In particular because firefighters are exposed to extreme thermal conditions, like high heat and flame even in summer, they have to alleviate the heat strain. In this study, we developed a new dual function vest (DF vest) to provide firefighters with body cooling and drinking water supply. The purpose of this study was to evaluate thermos-physiological effects and mobility while wearing the vest in simulated firefighting conditions.

Experimental Methods
The vest had four pockets to keep disposable iced packs (200 ml/pack × 4 packs = 800 ml) and flexible straws from each ice pack were arranged inside so that the ice could be used for drinking after it began to melt. The fabric of the vest consisted of stretchable fabric (85% nylon and 15% spandex). Eight young males (23 ± 2.5 yr in age, 171.9 ± 3.9 cm in height, and 68.3 ± 7.6kg in body weight) participated in four experimental conditions in a climate chamber of 30°C and 50%RH: Control [CON], Drinking Only [DO], Cooling Only [CO], Cooling & Drinking [CD]. A wear trial consisted of 30 min exercise followed by 20 min recovery and thermoregulatory and cardiovascular responses were measured. Mobility was evaluated through simulated firefighting tasks with heart rate and performance time completion based on Kim and Lee [1].

Results
The thermoregulatory and cardiovascular trials showed rectal (Tre), mean skin temperature (Tsk) and heart rate (HR) during recovery were lower for CD than for CON (P<0.05), while no significant differences between the four conditions were found during exercise. CO significantly reduced mean Tsk and HR and improved thermal sensation, whereas DO was effective for relieving thirst and lowering HR in recovery. The combined effect of skin cooling and fluid ingestion was synergistically manifested in Tre, Tsk and thermal sensation in recovery. For the mobility test, there was no differences in heart rate and work time completion between with/without the vest. In conclusion, the newly developed vest was evaluated as being effective to alleviate wearer’s heat strain and not to interrupt wearers’ mobility. The DF vest could be used by firefighters doing strenuous works under excessive heat stress to improve thermal comfort and dehydration without impairing mobility.
Figure 1. The time courses of rectal temperature (A) and the changes in rectal temperature for recovery (B). The CON, DO, CO and CD represent ‘control’, ‘drinking only’, ‘cooling only’ and ‘cooling with drinking’ conditions. *P<0.05, **P<0.01, and ***P<0.001.

Acknowledgments
This study was supported by the Fire Fighting Safety & 119 Rescue Technology Research and Development Program (MPSS-Fire Fighting Safety-2015-76; MPSS-Fire Fighting Safety-2015-82).
Keywords: A cooling vest, heat strain, drinking water, firefighters, body temperature

References:
IMPROVING SAFETY IN FIREFIGHTING USING ACTIVE BODY COOLING TECHNIQUES

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²Coimbra Institute of Engineering, Polytechnic Institute of Coimbra, Department of Mechanical Engineering, Portugal

Introduction

Firefighting requires long periods of hard work in very hot environments which are due to a great number of conditions that have to be considered. These conditions often lead to a continuous increase of the heat stored in the human body, promoting heat stress and more threatening heat-related illnesses, namely introversion (violent sweating, misleading, amnesia, etc.), superficial skin damages (pain and burn degree 1), heat stroke (fainting, stop of sweating, central nervous system alteration, etc.) and permanent injuries (burn degree greater than 1, brain damage or, in more serious cases, death). In order to increase the safety of firefighters, cooling techniques capable of mitigating these risks should be foreseen accordingly (1). The main objective of this work is highlight different protocols of body cooling techniques. The emphasis will be given to the identification and analysis of the effectiveness of body cooling techniques. It also aims to relate the fire intensity with the duration of the exposure to prevent the occurrence of any thermal condition that may constitute a human hazard.

Experiments

This study was done using the HuTheReg software (2), which predicts the thermophysiological response of the human body when exposed to a wide-range of conditions, namely different types of thermal environments (severe cold, cold, cool, neutral, warm, hot and very hot) with (or without) impinging thermal radiation, of exposure (uniform, sudden change and cyclical), of exercise intensities and of clothing. With this program a significant variety of data can be obtained, both for whole human body and for body regions.

The protocol adopted in the present study submits the firefighter to eight phases: neutral (stabilization), pre-fire period, followed by three firefighting - recovery stages. Three levels of impinging radiation intensity are considered (low, medium and high) and for each one three different body cooling techniques were tested (during recovery phases).

In the firefighting phases, the firefighter is equipped with the complete protective ensemble (Icl = 2.45 clo) and is facing the fire. It is assumed an impinging radiation flux of 3 kW/m² in the case of low fire intensity, 6 kW/m² for medium and 9 kW/m² for high intensity. The duration of the fire exposure was previously predicted by the software, indicating that for firefighter safety it must be no more than 20, 15 and 10 minutes for low, medium and high intensity, respectively.

During the recovery periods (of 15 minutes each), a body cooling strategy is applied and a normal ingestion of water is considered. The firefighter is dressed with the protective clothing, but without the helmet, the balaclava, the coat and the gloves (Icl = 1.53 clo). The three body cooling techniques tested are: traditional passive, by immersion of the hands and forearms in water at 20°C and by immersion of these limbs in water at 10°C.
Results
The thermal status of the firefighter was evaluated using the predictions for the evolution of the heat stored and the maximum exposure times to avoid the risk of threatening incidents. Table 1 shows the results predicted for the time delay to the onset of heat-related illnesses assuming a continuous firefighting condition. Figure 1 presents, for the case of medium intensity impinging radiation, the evolution with time of body heat stored and hypothalamus, rectal and maximum skin temperatures for the three different body cooling strategies tested: passive (a), immersion of the hands and forearms in water at 20°C (b) and immersion of the hands and forearms in water at 10°C (c).

As it can be observed, the passive cooling technique is not efficient enough to mitigate heat stress, but it is still valid when others cannot be used. Otherwise, the immersion of forearms and hands in cold water turned out to be the best alternative, with a slightly advantage when forearms and hands are immersed in water at 10°C. For the other radiation intensities, the cooling strategies maintain its relative effectiveness (3).

Table 1. Time delay (after firefighting start) for the onset of undesired illness, in continuous firefighting.

<table>
<thead>
<tr>
<th>Time delay</th>
<th>Impinging radiation intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Skin pain</td>
<td>130</td>
</tr>
<tr>
<td>Introversion</td>
<td>23</td>
</tr>
<tr>
<td>Heat stroke</td>
<td>45</td>
</tr>
<tr>
<td>Brain damage</td>
<td>64</td>
</tr>
<tr>
<td>Death</td>
<td>128</td>
</tr>
</tbody>
</table>

Fig. 1 (a) Passive cooling recovery in a shadow place far from the fire (firefighting with a medium intensity radiation from fire of $I_{imp} = 6 \text{ kW/m}^2$).

Fig. 1 (b) Active cooling by immersion of the hands and forearms in water at 20°C ($I_{imp} = 6 \text{ kW/m}^2$).

Fig. 1 (c) Active cooling by immersion of the hands and forearms in water at 10°C ($I_{imp} = 6 \text{ kW/m}^2$).

References:


GRAPHENE SURFACE MODIFICATION OF TEXTILES FOR PPE APPLICATIONS

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Abstract
Within the transnational Meranet-project “Graphene for Functionalization of Advanced Textiles” new functional surface modifications for technical textiles based on graphene was researched and developed. The aim of this project was to achieve the surface modification of textiles by graphene for developing innovative heat protective clothing. The Belgian project consortium was responsible for yarn impregnation, while the German project consortium was responsible for the development of aqueous graphene dispersions, textile application and manufacturing of prototypes. Graphene is known as a physical barrier, effectively preventing the penetration of heat and gases and has the potential to prevent the thermal decomposition of textiles. These qualities make graphene extremely interesting for applications in the field of Personal Protective Equipment (PPE).

Introduction
Graphene consists of single layers of carbon atoms arranged in planar six-membered rings. Monolayer graphene represents a semiconductor material with a linear dispersion distribution without having a band gap (1). As the number of layers increases an electronic band structure is formed (2). In graphene, a 1000-fold higher electron mobility is observed compared to silicon and a corresponding high electrical conductivity (3). Graphene is widely investigated in the field of electrical conductivity. It is used mostly in polymer/graphene nanocomposites. Usually a content of approx. 2wt% graphene is incorporated into the nanocomposites (4). It could be shown that the characteristics of graphene maintained within a polymer, as well as in an inorganic silicone matrix (5). Other properties, such as flame-retardancy (6), high tear resistance (7, 8) while remaining flexible and low vapour permeability are described in literature. While graphene nowadays is mainly used in polymer materials it is rarely applied in the textile sector. As graphene has many properties desirable for technical textiles such as heat protection clothing, antistatic and conductive textiles it is an interesting but few investigated materials for textile applications. Graphene combines conductivity with flame-retardant properties with high tear resistance while maintaining flexible. Usually a multistep application process is used for the functionalization of this kind of textiles. By the one-step graphene application further functionalization processes will no longer be necessary. Another advantage is the possible decrease of clothing thickness which comes along with weight reduction and an increase of the wear comfort.

Materials and experimental methods
Aqueous graphene dispersions containing graphene particles with different specific surface area, thickness and diameter were used. Different textiles with different fibers were used (e.g. CO, CO/PES/aramides) For textile application, the aqueous graphene dispersions (0.3 wt.% to 7.0 wt.%) were mixed with commercial available binder systems combined with textile auxiliaries such as thickener, antifoam and wetting agents. The textile application formulation
was produced by mixing the aqueous graphene dispersion with binder and textile auxiliaries according the manufacturer’s data for 5 minutes at 8000 U/min with an Ultraturrax of IKA. A textile coater was used to apply 100 µm of the application formulations on aramid fabrics and knittings. The coated textiles were dried and fixed at 150°C for 3 minutes. The graphene coated textiles were characterized according to the colour change caused by the coating and the distribution of graphene within the coating by scanning electron microscopy SEM (JEOL JSM-5610-LV). The flame retardancy was characterized according the EN ISO 15025. The comfort of the PPE was analysed with the sweating guarded hot plate and the thermal manikin Charlie.

**Results**

The combination of acrylate and polyurethane binder systems with aqueous graphene dispersions give the best performance. No problems by combining the aqueous graphene dispersion with wetting and antifoam agents as well as thickener could be observed. Depending on the amount of thickener used slightly or highly viscous application formulations were received. After the graphene application on the textile, it can be seen, that with higher graphene concentration the coating is getting darker. All coatings have a greyish to black colour. This impact of colour is caused by the graphene itself. The used graphene dispersions contain no single layer graphene but a few layer graphene which is coloured. Scanning electron microscopy SEM pictures show that there is continuous film of graphene coating on top of the filaments of the textile. The brighter spots within this film are graphene agglomerates. The PES/CO fabrics show a 19% less afterglow time in case of foulard impregnation and a 74% less afterglow time in case of coating. The results show that the flame retardant effect on textiles by application of graphene is possible. The investigation of the comfort is done, but the analysis is still ongoing.

**Conclusion**

The properties of graphene, such as high electrical conductivity and flame retardancy, make it interesting for textile applications especially in the field of PPE. By using graphene coatings, a single-stage process is possible. Therefore, the material used for PPE can then be thinner and lighter, which may increase the mobility of the user. Different finishing techniques, binder systems and textile auxiliaries were investigated for studying the stability and compatibility of aqueous graphene dispersions for textile applications. The final analysis of the results is still going and the final report of this research project will be finished in March 2018.

**Acknowledgements**

The research project 03X0157A “GRAFAT” was founded by the Federal Ministry for education and research (BMBF).

**Keywords:** graphene, textile application, PPE, aqueous dispersion

**References:**

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HOME OFFICE PERSONAL PROTECTIVE EQUIPMENT STANDARDS – UPDATES AND DEVELOPMENT WORK

Tom Payne
Home Office Centre for Applied Science and Technology

Abstract

Introduction
The Home Office Centre for Applied Science and Technology (CAST) has researched, written and managed a range of test standards relating to personal protective equipment for frontline policing for several decades. These include:
- Body Armour (Pub No. 012/17) (1)
- Portable Ballistic Protection (Pub No. 47/11) (2)
- Public Order Helmets (Pub No. 21/04) (3)
- Blunt Trauma Protectors (Pub No. 20/07) (4)
- Slash Resistant Materials (Pub No. 48/05) (5)

CAST are continually engaged in activities to ensure the test methods and specifications within standards are fit for purpose and meet the needs of the user community. This paper outlines the process followed to set standards, with a focus on body armour and slash resistant materials standards.

Standards Development Process
All standards are developed to enhance the safety and operational effectiveness of UK policing. Therefore CAST engages heavily with end users throughout the development process to ensure the standards promote equipment that is fundamentally fit for purpose.

1. The initial phase of any test standard is a user requirement that has been developed with, and agreed by, senior users from the police community.
2. CAST reviews existing standards and the current state of the art in academic literature to identify where research activities are necessary.
3. The requisite research is either conducted in house or externally under CAST supervision.
4. This research directly informs the formulation of test specifications and methods in the standard.
5. The final draft document is peer-reviewed by international government representatives prior to final approvals by the UK policing customer.

Home Office Body Armour Standard
The most recent development is the Home Office Body Armour Standard (2017), which represents the latest advancement in the evaluation of ballistic- and stab-resistant body armour for use by UK law enforcement, wider emergency services and also internationally. This is a revision to the internationally-recognised HOSDB Standard (2007) and is the first major body armour standard that has been used globally for 10 years. It represents a significant improvement in test methods that are more consistent, practical, and representative of current operational needs of UK law enforcement.

Key improvements have been made on the testing of shaped body armour. This focused on the development realistic female-shaped test surrogates for the assessment of female armour and
representative male torso surrogates for plate testing, enabling a more realistic fit and body armour-surrogate interactions. Another key advancement has been in quality assurance where CAST has engaged with experts within the MOD to generate statistical software that enables a greater confidence in armour performance for use within production quality testing and in-life monitoring.

**Slash Resistant Materials Standard**

Other notable recent development work has been conducted on slash resistant materials to protect against short duration swipe attacks of an edged weapon across the body. CAST are engaged in activities to update the existing test standard with specifications, methods and assessment criteria that are more representative of sustained impacts.

**Key Words:** Home Office, Body Armour, Personal Protective Equipment, Standard  

**References:**  

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SWEAT DISTRIBUTION AND PERCEIVED WETNESS ACROSS THE HUMAN FOOT

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²adidas FUTURE Sport Science, Herzogenaurach, Germany

Introduction
Investigations of intra-segmental sweat distribution at the foot consistently report sweat rates to be greatest from the dorsal surface compared to the plantar surface (~70% and ~30% respectively) (1,2). However, detailed comparisons of foot sweat rates from existing literature are difficult due to differing ambient temperatures, heating techniques, exercise modes and socks/footwear used. In addition, the relationship between sweating on the foot and perceived skin wetness is unknown. This study investigated regional foot sweat distribution to aid footwear design and assessed the relationship between sweat distribution and perceived wetness.

Methods
14 trained female runners performed 60 minutes of treadmill running with ambient conditions of 25°C, 50% RH. 35 minutes of running were performed at a low intensity (55% maximal heart rate) followed by 25 minutes at a higher intensity (75% maximal heart rate). Sweat rates from the right foot were measured at 14 zones using technical absorbent material and a 100% cotton sock applied during the last 5 minutes of each work intensity. Local sweat rates were derived from changes in pad mass. Infrared images pre and post pad application were recorded to evaluate local and mean foot skin temperature. Wetness perception was assessed prior to pad application. Participants exercised in standardised clothing, socks and running shoes.

Results
Heart rates averaged 134 ± 3 bpm and 157 ± 2 bpm during low and high exercise intensities respectively. Corresponding core temperatures were 37.8 ± 0.2°C and 38.2 ± 0.3°C. Participants presented evidence for a non-uniform distribution of sweating on the foot. Highest local sweat rates were observed from the medial ankle, medial dorsal and central dorsal. Lowest local sweat rates were observed from the toes. Sweat rate significantly decreased with exercise intensity at the arch, ball and outer foot regions (p < 0.05). Participants sensed differences in wetness at different zones (dorsal, toes, heel, sole; p < 0.01) with wetness perception increasing significantly with exercise intensity (p < 0.05). Despite the toes having the lowest sweat rates, they were perceived as being one of the wettest zones during both exercise intensities.

Conclusion
The present study provides a detailed view of sweating across the foot surface for trained female runners. In accordance with previous studies, sweat rates were greater from the dorsal surface compared to the plantar surface. Perceptions of wetness increased with exercise intensity across all zones but sensations of wetness did not correspond with areas of high sweat production. It is important to consider that footwear comfort may not be dominated by a single zone and possibly not the zone with the highest sweat production.
**Keywords:** Intra-regional sweating; feet; sweat mapping; exercise; footwear comfort.

**References:**


EMERGING FACTORS RELATED TO THE DESIGN, SELECTION, AND USE OF PROTECTIVE CLOTHING AGAINST HIGHLY INFECTIONOUS DISEASES

Jeffrey Stull, Christina Stull
International Personnel Protection, Inc. (USA)

Introduction
In 2014 through early 2015, Ebola raged through the West African countries of Guinea, Liberia, and Sierra Leone leading to an estimated 28,300 cases with 11,315 fatalities, also including a significant portion of healthcare workers. Undoubtedly, the infection and ultimate death of several doctors, nurses, and other medical personnel was due to failure to use needed forms of personnel protective equipment; however many succumbed to the disease even when seemingly having adequate protection. Case in point, two U.S. nurses treating Liberian patient Thomas Eric Duncan ended up with Ebola Viral Disease despite following the U.S Center for Disease Control guidelines for PPE for highly infection diseases. The lessons learned from the spread of EVD created significant ramifications for the design, selection, and use of PPE for protection against highly infectious diseases. A multitude of efforts were launched for improving both PPE and the practices for its use global with organizations such as the World Health Organization, Doctors without Borders, and the International Medical Corps attempting to redefine medical personnel protective clothing practices in West Africa.

Development Approach
This paper describes two different approaches for U.S. government funded design efforts aimed at creating an ensemble approach for using a reconfigured garment systems and head/face protection coupled with gloves and footwear for West African use as well as industrialized nations. Specific design features were created to provide an overall liquid-resistant ensemble with improved levels of liquid integrity while minimizing the potential for heat strain when used in hot/humid environments. These designs supported donning and doffing procedures involving fewer steps and focused on reducing the potential for contaminant transfer, a PPE factor suspected of contributed to healthcare worker infections in both West Africa and Dallas, Texas. Photographs of the two different ensembles are shown in Figures 1 and 2.
Principal Findings
The new ensemble designs and practices for their use, particularly doffing and decontamination approaches, have demanded shifts in the how clothing is developed, selected, and used for highly infectious diseases and pointed to the inadequacy of both local and international standards. Domestic and international field testing proved instrumental for optimizing specific ensemble design approaches and utility.

Acknowledgement
This research was supported by the U.S. Agency for International Development and the U.S. Department of Defense.
SEERSUCKER WOVEN FABRICS AS A THERMAL INSULATOR

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Abstract
The aim of work was to investigate the thermal insulation properties of the seersucker woven fabrics. The structure of the seersucker fabrics was assessed using the 3D laser scanning. Thermal insulation properties in dry and wet state were measured by means of the Alambeta device. The results confirmed the ability of the seersucker woven fabrics to ensure high thermal insulation and good physiological comfort.

Introduction
The seersucker woven fabrics create a unique 3D woven structure. A typical seersucker fabric is characterized by an occurring the puckered strips in warp direction. Such 3D structure is usually received on loom by an application of two warps of different tension [1, 2]. The wrinkled-striped structure of the seersucker fabrics causes that the fabrics are characterized by good comfort properties. Due to existing the air gaps between the seersucker fabrics and surface of human body or surface of apparel product worn under the clothing made of the seersucker fabrics the fabrics ensure high thermal insulation. Additionally, the air gaps simplify the gas exchange between the human body and surroundings.

Experimental
The aim of work was to investigate the thermal insulation properties of the seersucker woven fabrics. 4 variants of the seersucker fabrics of different structure were the objects of the investigation. The fabrics were manufactured on the basis of the same set of warps: basic and puckering. Different structure of fabrics was received by application of different weft yarns. All fabric variants were measured in the range of their basic structural parameters characterizing the seersucker effect. The measurement was performed using the 3D laser scanning and scanned data processing.
Thermal insulation properties of the investigated fabrics were determined using the Alambeta device. Measurements with the Alambeta were performed in dry and wet state of the seersucker fabrics. The results were analysed in the aspect of the influence of the seersucker effect on the thermal resistance of the fabrics. Moreover, the results for dry and wet fabrics were compared in order to assess the ability of fabrics to ensure physiological comfort [3]. Obtained results confirmed that the seersucker woven fabrics ensure good thermal insulation and physiological comfort. The thermal resistance of the seersucker woven fabrics is significantly higher than the thermal resistance of typical flat woven fabrics. Thermal absorptivity of the seersucker fabrics in wet state is lower than 300 Wm\(^{-2}\) s\(^{1/2}\) K\(^{-1}\) what qualifies the fabrics as materials ensuring good physiological comfort.

**Acknowledgment**
This work is financed by National Science Centre, Poland in the frame of the project titled „Geometrical mechanical and biomechanical parameterization of the three-dimensional woven structures”, project No. 2016/23/B/ST8/02041.

**Key words:** Seersucker woven fabrics, laser scanning, thermal resistance, thermal absorptivity.

**References:**
Posters
A REVIEW ON THERMAL PROTECTION

Juliana Cruz1,2,3, Ana Leitão1,2,3, Catarina Guise3, Fernando Ferreira2,3, Raul Fangueiro1,2,3

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22C2T
3University of Minho
4Inovafil Fiação S.A.

Introduction
In a situation where an individual is under an extreme environment, clothing may be a decisive factor in his survival. In order to protect the individual from his surrounding harsh environment, clothing must promote the thermal insulation providing the required level of protection. The choice of clothing materials may undergo various approaches, including materials consisting of intrinsically fire-retardant fibers, such as aramids, or materials in which heat-resistant additives or finishes may be applicable (1). A solution may also be the combination of layers: usually a dense and heavy layer surface coated by an aluminum layer in order to promote thermal insulation. Weight is the most important restriction to be considered, as may condition the user's mobility in addition to becoming much more uncomfortable in hot environments (2). In this review, new technologies to provide thermal protection and comfort are presented.

Shape Memory Polymers
Shape Memory Polymers (SMP) or polymer-based hydrogels are examples of structures capable of interacting with the environment. These materials are sensitive to factors such as temperature, pH, light and/or salts, modifying their shape or size when stimulated, being able to be incorporated in polymeric materials and in coatings of fibrous structures in order to promote their responsive character (3)(4). Among these materials are polyurethane (PU), polyester, polyhydroxyproline, polysilamine and some sensitive hydrogels including poly (N-isopropylacrylamide) (PNIPAAm) hydrogels, polythiophene gel, among others. SMP are also sensitive to mechanical, electrical and magnetic stimuli, and can alter their shape, position, stiffness and other static and dynamic characteristics in response. These materials have additional advantages compared to other materials, since they are mostly cost-effective and easier to handle, and can be programmed at the activation temperature thanks to the ease of developing copolymers with the use of additions. Membranes containing SMP technology, such as “DiAPLEX®” and “Dermizax®”, from Mitsubishi Heavy Industries Ltd, and Toray Industries Inc, respectively, are already available on the market.

Vili et al. studied the application of shape memory materials in fabric structures for home textile application (curtains, partitions and tapestries). The idea is that these instill in these textiles the ability to react to ambient stimuli, such as temperature, in addition to complying with their conventional application (5), (6).

PCM Nanostructured
PCMs can be encapsulated in microcapsules or nanocapsules in order to reduce their reactivity to the external environment as well as to control the volume of material changes stored during the phase change period. PCM nanocapsules can be added in the fiber spinning phase or as
textile coatings during the finishing process using a binder, such as polyurethane (7), (8). PCM nanofibers prepared by electrospinning and coaxial electrospinning are among the other methods used in textiles (9).

Nanoparticles and microcapsules based on PNIPAAm can also be used as coatings in order to respond to the stimulus temperature, in a dynamic, adaptive and autonomous way, to the requests of the environment. Polymers such as polyether, poly (9,9-dioclyfluorene-cobenzothiadiazole) and poly (9,9-dioclyfluorene), converted to nano form, obtained by an emulsion technique, are potential candidates for use in the textile functionalization (10).

The incorporation of metal nanoparticles into form memory polymers is another approach to obtain a composite with multifunctional properties. The incorporation of carbon nanotubes and carbon nanofibers into SMPs is an example of this inclusion, resulting in a composite with shape memory and electroactive properties (11). In addition, gold particles have also been incorporated into polyurethane-based polymers to obtain nanocomposites capable of being pelletised by an external stimulus based on a low-intensity laser (12). Although it is known that silica-based particles - a compound used as crosslinking agent in composite reinforcement - deteriorate the memory effect of a polymer, Zhang et al. demonstrated that SiO2 particles previously crosslinked with ε-caprolactone confer excellent mechanical properties on the polymer composite in addition to shape memory properties (13).

Polymer coatings with memory materials demonstrate various thermal stability problems as well as lack of uniformity and reproducibility of the coating. In fact, deposition coatings are rarely tackled due to various processing problems and coating properties (5), (6).

Acknowledgement
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References:


CAN PROFESSIONAL FOOTWEAR HELP REDUCE FATIGUE OF PROFESSIONALS IN THE LOGISTICS SECTOR?

Ana Rita Pedrosa
Lavoro

Introduction
So that the professional footwear - especially used by professionals of the logistics sector - favors the contact of the foot with the floor, the shoes must protect the zones of hyperpressure: heel, internal arch, metatarsals and digital pulp of the hallux. From the work of a multidisciplinary team, coordinated by SPODOS-Foot Science Center, Lavoro created an innovative sole, inspired by the football universe, in which these areas of hyperpression are eased through the correct distribution of forces.

Experimental
SPODOS-Foot Science Center has identified the need for logistics workers to wear professional shoes that enhance their safety and respond more efficiently to the challenges of their work: long periods of standing, constant movements, cargo and goods support. An analysis of the normal walking cycle of an adult on a horizontal surface in a walking dynamics shows that the weight is not evenly distributed in the sole of the foot, there are areas under more pressure, the so-called areas of hyperpressure: heel, inner arch, metatarsals and digital pulp of the hallux. It is these areas that bear the heaviest weight and therefore must be protected from impact. For the development of a new sole, SPODOS-Foot Science Center, inspired by the lessons of football, tested the use of flat pythons as a resource to benefit the contact of the foot with the soil, precisely protecting the areas of hyperpression. The resulting sole, the ‘CUP’ is composed of a series of flat pythons strategically distributed in order to respect the natural walk cycle and to precisely protect the areas of the foot that are further damaged by the pressure resulting from walking.

![Figure 1. Lavoro CUP’ sole: distribution of pythons in the areas of hyperpression.](image)

Results
A study from UMANA - Center for Biomechanical Analysis, based in Vigo, Spain, concluded that the Lavoro CUP model presents an index of 8.5 in 10 in the field of footing uniformity; an index of 7.3 in 10 in the tread stability domain; an index of 7.5 in 10 in the area of dynamic adaptation; a safety index of 8.6 out of 10 in the area of joint damage. In conclusion, the study shows a global biomechanical assessment of 7.9 out of 10, taken as EXCELLENT.
References:
COMPARATION OF THERMAL INSULATION OF PROTECTIVE GLOVES WITH PASSIVE AND ACTIVE HEATING SYSTEMS

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Introduction
The number of people worked in cold environments is a noticeable group among the total number of people employed in hazardous conditions by factors related to the working environment. According to the current state of the art various practical actions to mitigate the effects of cold environment conditions on thermal comfort of work are undertaken (1,2). Currently, protective products are increasingly multifunctional and are characterized by more and more advanced solutions that increase the thermal properties. In practice, gloves for protection against cold should be characterized primarily by thermal insulation to the highest performance level specified in accordance with EN 511:2006 (3). Gloves with passive and active heating system can be an alternative for standards products (4).

Experimental
The purpose of the study was to compare the thermal insulation of gloves with passive and active heating systems taking into account ambient temperatures (-15, -10, 0 and +5°C). Thermal insulation was performed on a thermal hand model for two heated gloves containing different heat sources (active and passive) with reference to EN 511:2006 standards.

Results
The results confirmed that the use of additional heat source (active or passive) allows for obtaining the higher values of thermal insulation, expressed by the change in the performance level.

The obtained results show that active systems are more effective than the tested passive heat sources (Figure 1). Depending on the degree of exposure of the worker to cold environment, it is advisable to wear gloves additionally equipped with passive or active heat sources.
**Figure 1.** The increase in thermal insulation expressed in the change of the performance level of the glove with active heating system in comparison to the glove with inactive system.

**Acknowledgement**

The paper is based on the results of the 4th stage of the multi-annual program "Improving safety and working conditions" funded by the Ministry of Family, Labour and Social Policy in 2017-2019. Coordinator: Central Institute for Labour Protection - National Research Institute, Poland.

**References:**

3. EN 511:2006 „Protective gloves against cold” EN 511:2009 The European Standard has the status of a Polish Standard,
DESIGN POTENTIALS OF MAGNETIC YARNS

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Abstract
Magnetism holds a strong potential as a design material due to the array of possible expressions based on its fundamental behaviours of attraction and repulsion. The magnetic phenomenon presents itself simultaneously as visual and non-visual material through its quality of being imperceptible under certain conditions until manifested in some way, such as physical interaction or electronic control. This balancing of physical constants, material and immaterial considerations of magnetic phenomenon, become a rich site for exploration and experimentation when combined with the immense variables available in textile design such as yarn attributes (fiber composition; yarn number, twist, and structure) and textile structure (woven, non-woven, knit, twisted and interlaced) [1]. Therefore, the use of magnetism as a design material holds a strong potential for dynamic and responsive textile expressions when used in composition with one another. While the discourse surrounding the material-immaterial relationship is active and present across various design disciplines [2,3,4], the representation of magnetic phenomenon as a design material remains underrepresented in the field of textile design. This experiment illustrates a method of creating yarns that are responsive to magnetic fields through a process of hand-painting natural, synthetic, and combination yarns with a widely-available ferromagnetic solution. Ferrite is commonly used to condense and thereby enhance magnetic fields [5], therefore the creation of ferritic yarns aims to increase the material selection for those working with magnetism or electromagnetism in textiles, further opening up design possibilities for research areas such as textile-based antennas [6, 7, 8].

Experiment
Each yarn sample was trimmed to measure approximately 10 cm in length and was grouped in bundles to form tassels. Where heavier yarn weights were used, a smaller number of threads were represented in the tassel (Fig. 1). Ferrofluid was applied to the yarns in their tassel forms through the technique of hand-painting with a paintbrush and leaving them to air-dry for 24-48 hours.
Magnetic Yarn Attributes
The ferrofluid-treated tassels were explored individually by anchoring the tassels to create a central point from which all movement would arise. A magnetic field was then applied using 6 stacked neodymium magnets. The magnetic field was manipulated by hand movement around the tassel while the yarn was visually assessed for its ability to lift and drop as the magnetic field was applied and then removed. Characteristics of the magnetic yarns were noted with comments on their design potential for woven textiles, such as intensity of magnetic lift (high/moderate/low) (Fig. 2), mobility of the yarn (high/moderate/low), perceived weight of the yarn (light, heavy), stiffness, stretchiness, and the yarn’s ability to hold sculptural form. Yarns that did not exhibit any notable magnetic qualities were identified as being “static”. Further characteristics of the yarns post-ferritic treatment were the documentation of absorption quality (good/neutral/poor), yarn quality (flexible/soft/stiff/rough), and the yarn colour (light/medium/dark brown, and black).
Results
Based on their attributes and the magnetic responses demonstrated, yarns were categorized into the following groups of woven textile design possibilities: floats, light weaves, textured, structured weaves, sculptural, and cut/looped pile. Fine yarns that maintained softness, flexibility, and lightness, after the application of ferrofluid were identified as being suitable for light weaves and woven designs with high mobility floats (Fig. 3). Heavier yarns and those that exhibited stiffness were identified as being suitable for textured, heavier weaves, and in some cases, sculptural designs. Some yarns were identified as having potential in a cut or looped pile based on the texture, weight, and flexibility exhibited post-treatment. Many of the yarns overlap across the proposed design possibilities. The author recognizes that there is an untold amount of possibilities within woven textile design, however these suggestions are intended to serve as a starting place for further design experimentation.

Conclusion
This experiment describes a process of creating magnetic yarns using commercially-available ferromagnetic fluid and documents pre-and post-treatment yarn attributes and post-treatment behaviour when exposed to a magnetic field. It identifies magnetic yarn characteristics such as magnetic lift, and level of mobility, and states the three key variables to be considered when working with magnetic yarns: absorption ability, intensity of magnetic field, and physical yarn weight. Finally, the experiment results suggest design potentials for magnetic yarns in woven textile designs. The experiment undertaken here was exercised through a process of practice-based design research. It aims to expand upon the materials available to designers working with magnetism and electromagnetism, and attempts to open up design possibilities for research areas such as textile-based antennas.

Acknowledgement
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References:
HEAT RELEASING PERFORMANCE TEST FOR HYGROSCOPIC AND EXOTHERMIC MATERIALS

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Introduction
Recently, new type of temperature adaptable materials known as heat releasing fibers have been developed and commercialized. These fibers release heat when moisture is absorbed, which is called heat of sorption. However, the test method to quantify the released heat or microclimate change by the material is not clearly established. In this study, new test method to test heat releasing materials at transient condition of temperature and humidity change was attempted.

Experimental
To investigate the properties of heat releasing materials, wool (WL) and hygroscopic/exothermic materials (HE) were evaluated in three types of specimens (fiber, fabric and garment) under various environmental conditions in order to compare their heat releasing performance. Wool has a greater hygroscopic heat generation than any other natural fibers. HE is a synthetic fiber that has been developed to release heat by combining moisture with hygroscopic heat generation technology. The three types of specimens were tested under a steady state using the sweating guarded hotplate(1), the automated Human-Clothing-Environment (HCE) simulator(2), and the sweating thermal manikin(3). Thermal resistance (Rct), water vapor resistance (Ret) and moisture permeability index (im) were comparatively analyzed using the three different test methods.

Results
In the case of the heat releasing material, the steady state test does not illuminate the difference in performance between HE and WL. The traditional thermal resistance is measured by the standard stationary methods (for example, those involving the use of a sweating hot plate apparatus). Heat releasing properties of fiber and fabric type specimens were compared at transient conditions. As the heat generated by the heat releasing material dissipated, there was effect on the microclimate. The microclimate humidity for the HE was lower than the WL. The results show that the hygroscopic and exothermic fibers have a higher capacity to absorb moisture in the microclimate than the wool. The heat regulation and vapor regulation properties for HE was higher than the WL. These differences are due to the fact that hygroscopic and exothermic fibers have a greater moisture regain than wool fibers. The three types of specimens were tested under non-isothermal condition to evaluate the behavior of heat releasing properties. Higher values of the buffering parameters indicate advantageous in terms of temperature and moisture vapor modulating capabilities in transient conditions.

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1. ISO 11092 (2014) Textiles —Physiological effects —Measurement of thermal and water vapour resistance under steady state conditions
DEVELOPMENT AND ASSESSMENT OF A TECHNICAL MATERIAL FOR CONSTRUCTION WORKWEARS

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Introduction
Construction work mostly involves outdoor tasks, and the workers are exposed to hot or cold external environments during work, which they must endure. In particular, as the capillaries in the human body contract and skin temperature falls in winter, their heat dissipation is reduced (1). Long-term exposure to cold environments reduces the comfort and agility, leading to the reduced task-performance and high risk of injury. Currently available workwear is made of needle punched insulation and fleece to enhance the heat-retention capacity. However, despite excellent heat retention, materials such as down and wellon are vulnerable to moisture and highly expensive depending on the contents, so that their use in workwear is undesirable. Thus, continuous efforts for developing new materials, which will efficiently improve the heat retention capacity, are essential. Furthermore, construction work requires workers to deliver packages such as iron bar and timber, and approximately 50–60 % of industrial accidents in Korea are directly or indirectly related to the delivery tasks (2). This has led the present study for the development and assessment of an advanced "technical material" for the workwear of construction workers, which can reduce the cold stress and minimize the physical pressure. The study also examined the compatibility of the new material with workwear.

Experimental

The novel "technical material" was developed based on the 3D Spacer Fabric that exhibits the excellent thermal-retention capacity and impact absorption characteristics. First, the SolidWorks 2016 (Dassault systems, Korea) program was used to model four "technical material" samples (A, B, C, and D) that differ in terms of "side width" and "leg height" (Figure 1). The samples were obtained by 3D-printing using TPU(Thermoplastic poly urethane), which demonstrates enhanced flexibility and shock absorption. The first experiment was carried out

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Illustration of the technical material.}
\end{figure}
in an environmental chamber whose conditions were set to the winter environment (temperature 5±1 °C, relative humidity 60±5 %). The sample was placed in a pocket made of 100% polyester, which was placed on a heating plate set at 30°C (average skin temperature in winter). The thermistor (LT-8AB, Gram Co., Japan) was used every 10, 20, and 30 min to measure the surface and internal temperatures of the "technical material", and FLIR30 (FLIR Systems, Inc.) was used to produce the thermogram. The second experiment was a 3D simulation of the "technical material" to estimate its function as a protective pad. SolidWorks was used to place the "technical material" on the shoulder of the 3D model of the human body, and the weight of a pipe was applied, after which the structural changes in the pad according to the weight load on the shoulder were examined.

**Results**

First, the surface temperature variation measured by the thermistor was analyzed time-dependent increase in temperature from sample A and C with low "leg height". In particular, after 30 min, the temperature of sample C was approximately 6.3 % higher than that of sample A, indicating that a larger "side width" is correlated with higher surface temperature. The sample with the highest surface temperature was D; after 30 min, the temperatures of samples C and D were higher than those of the other samples. The larger the "leg height" and "side width", the more efficient the surface temperature. The temperature of sample B was the lowest, indicating that a thicker "leg height" is correlated with lower heat conductivity when the "side width" is small. On the other hand, the internal temperature of samples D and A was the highest and lowest, respectively. After 30 min, sample D and B had the highest and lowest internal temperature, respectively. In addition, after turning off the heating plate, sample D maintained its surface and internal temperature, but those of sample C showed a tendency to decrease while sample A had the lowest. It was confirmed that it is suitable for cold environment where "leg height" is high and "side width" is large, that is, the pore size is small. Furthermore, the thermogram images showed the similar tendency as the surface temperature for all samples.

Next, the interpretation of 3D simulated structures showed that the position of the weight load did not alter the displacement position of the protective pad. Although the weight load between the protective pad and human body was not reduced due to the law of action and reaction, the pressure felt by the human body spread out to an area larger than the weight load, so that the relative pressure was lower. The present study ultimately aims to develop safe workwear material for construction workers that can protect them from external as well as work environments, by combining appropriate factors of the "technical material" that will protect the human body and help maintain a stable temperature, and hence, provide comfort during winter.

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**References:**

DEVELOPMENT OF PPE GARMENT PROTOTYPES FOR PESTICIDE OPERATORS

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Introduction
In addition to performance requirements, factors such as fit, design, color, cost, care, and availability are important for the user acceptance of certified garments. A study was conducted as part of the International Consortium for PPE for Pesticide and Re-entry Workers to develop and evaluate garment prototypes that can be used for reusable PPE that meet the Level 1 and/or Level 2 requirements for ISO 27065. For this study knowledge and information gained in previous years was used to develop two garment prototypes. Level 1 fabric Fabric used for a 2015 study entitled “Determination of worker re-entry exposure associated to typical re-entry activities (shoot lifting and harvesting) in vines in France” was used for the prototypes. This presentation focuses on functional clothing design of clothing worn by pesticide operators. Protection, fit, comfort and visual appearance were considered while designing the garment prototypes. User input was obtained in small group settings and the information used for modifications.

Methodology
One and two piece garments were designed as both types of garment are prevalent in the agricultural sector. In some countries (e.g., France) one-piece coveralls are more commonly used whereas in other countries 2-piece is the norm (e.g., Brazil). Four garment designs, based on typical workwear, with features added for ease of donning and doffing, balance between protection and comfort and ease of movement were proposed for the initial review. Visual appeal was achieved by color and overall style. From the initial sketches, a 2-piece garment and a one-piece garment were selected for further refinement. Prototype 1 consisted of a jacket style top with raised collar, elasticized cuff and curved back for added protection. Raglan sleeves, gussets and pleat at the back was for ease of movement. An opening with mesh fabric provided ventilation for comfort. The pant back had an elasticized waist with a curved raised back to protect while bending. The curved seam at the back was for ease of movement and patch pockets with flaps met the design requirements for ISO 27065 garments.
Prototype 2, a one-piece garment, had applicable design features similar to Prototype 1. In addition, it has a 2-zipper design for easy donning and doffing. A CAD system was used to make paper patterns for medium and large sizes based on the sketches. Two sets of garments (one each of M and L size) were sent to Spain and France for evaluation by user groups. In Spain the garments were evaluated as part of three group discussions by farmers and greenhouse personnel. In France the garments were evaluated by two groups of farmers (mainly cereals, orchards or multicrop-livestock farming). Participants from user group who wear Size M and Size L were asked to volunteer to have evaluate the fit and design features of the prototypes and respond to questionnaire that included questions regarding preference for the garment type, color and special features. The information provided by the users was used to modify the garment designs.

Figure 1. Prototype 1 sketches with design features.

Figure 2. Prototype 2 sketches with design features.
Results
In Spain, 2-piece garment with detachable hood is preferred; Fig. 3a includes the detachable hood designed that can be used for Prototype 1 and 2. In France 1-piece or 2-pieces were preferred in equal proportion. The users prefer pocket with flaps on the chest instead of pockets on the side of the pants. Other suggestions from users were a. sleeve cuffs with Velcro and b. zip at the bottom of the pant for ease of donning and doffing over boots. Bottle green and dark grey color combination was preferred.

![Diagram of detachable hood and zipper at the bottom of the pant]

**Figure 3.** a. Detachable hood b. zipper at the bottom of the pant.

Acknowledgement
This study was conducted as part of the International Consortium for PPE for Pesticide Operators and re-entry workers project. Special thanks to Klopman International for providing the fabrics; Krojaštvo Rožman, Branko Rožman s.p. for the development of paper patterns and manufacturing the garment prototypes for the study; and Asociación Empresarial para la Protección de las Plantas (APELA) for their assistance in obtaining user input.
EVALUATION OF MANUAL DEXTERITY OF PROTECTIVE GLOVES WITH HEATING ELEMENTS FOR COLD ENVIRONMENT

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Introduction
One of the working environments are cold ambient conditions, where air temperatures equal to or less than 10°C (1). The cold environment can influence the whole body, causing the cooling of an organism and impair human abilities (2). Exposure to cold temperatures can significantly affect finger/hand dexterity. Gloves used to protect workers exposed to cold temperature should have appropriate insulation properties that depend on the design and construction of the glove primarily associated with the type of material used.

One of the innovative solutions to protect and improve the comfort of working in the cold environment is equipping an employee with an additional source of heat in the form of heating elements.

The research about the impact of construction of protective gloves designed for the cold environment including the ergonomic factors associated with occupational exposure and also shape and type of surface of the facilities being handled is described in literature (3). However, the influence of placing heating elements on manual dexterity associated with the comfort of professional activities has not been described so far.

Experimental
The purpose of the study was to evaluate manual dexterity and the convenience of using protective gloves designed for use in cold environments equipped with heating elements. Three types of gloves were tested: mitt (variant 1), five-finger (variant 2) and knitwear for a five-finger glove (variant 3). The glove equipment used a heating element made of mineral beams differing in size. The heating elements of 10 g and 24 g were chosen in a corresponding shape for mitts and five-finger gloves. The ergonomic properties of the protective gloves were also evaluated according to the position of the heating element: in the palm part, dorsal part and in both locations simultaneously.

For all dependencies, manual dexterity tests were performed and the following parameters were evaluated:

**Test 1** - Dynamometric Cylinder and Cylinder Test - maximum strength and retention force
**Test 2** - Purdue Pegboard - Number of pins
**Test 3** - Simulation of work activities - Retrieval of an element - Retention time of an element in a deflected position [s]
**Test 4** - Simulation of work activities - Retention of the element - Distance to which the participants' fingers have moved [mm], Table extended at 2 cm in 10 seconds

Fig 1. Localization of heating elements in the palm and dorsal part.
**Test 5 - Simulating of work activities - Screwing an element** - The distance at which the machine's marker has moved relative to the initial value [mm] in 10s

**Results**

Based on the results obtained, statistically significant influence of protective glove design on all parameters (test 1-5) of manual dexterity and comfort of use of protective gloves was found. In the case of the mitts (variant 1), the lower values of the maximum force, maintenance, number of elements and twisting of the element were lower than for the 5-finger gloves (variant 2). In addition, in the case of the five-finger glove (variant 2), lower values for the number of elements were observed and higher values of the twisting parameter than for the five-finger glove (variant 3).

The statistically significant effect of the heating element on the manual dexterity parameters was also statistically significant, except for the parameter of the extrusion factor (test 3). In the absence of a heating element, higher values of the maximum force, maintenance and twisting force of the element were observed than those of the heating element. On the other hand, for the number of elements, the lower values for models in mitts were observed than for models in five-finger gloves. No differences were observed between elements heating of different mass specimens in the general gloves.

By investigating the influence of the location of the heating element on the assessment of manual dexterity and the assessment of the convenience of use in protective gloves, the statistical significance of the tested effect on the dexterity parameters in tests 1-5 and the assessment of manual activities and feelings of effort in tests 1-5 in all types of protective gloves were found.

In conclusion, the glove construction and the shape of the heating element affect the dexterity, while the location of the element does not affect the manual dexterity and the comfort of use of the protective gloves.

**Acknowledgement**

The work is based on the results of COLDPRO project: ‘The use of active ecological mineral compounds in the production of cold-protective gloves and footwear’ funded in the years 2015-2018 by the National Centre for Research and Development.

**References:***

Introduction
Researches and technicians of the Laboratory of the QUEPIA - Program of Quality for Personal Protection Equipment in Agriculture, of Engineering and Automation Centre (CEA) of the Agronomy Institute (IAC), in Jundiaí-SP, Brazil, has been conducting the cabin spray test in accordance with ISO 17491-4, method A [1] for research and as a notify body for certification and observed variability in the spray distribution pattern. A first study to document the problems and propose solutions was conducted by Ramos et al, 2015 [2]. This study, which evaluated different settings changing number and type of nozzles in the spray boom, showed the possibility and advantage of the exchange the hollow cone nozzle recommended in the standard by XR 8001 flat fan nozzle at 400 kpa. However, this first study fixed the flow rate as the ISO specification, in this way, was used 400 kPa to flat fan and 300 kPa to hollow cone. This difference in pressure could mean two main problems to the test. The first is that the volume arriving the subject was much bigger in the flat fan than in the hollow cone nozzle, for the same sprayed volume, and this difference can change the pass/fail level. The second is that the spraying system of cabin must have a opening valve which open in a specific pressure. Vary the pressure between method A and B tests means change the valve, what is not a simple task. Thus, if it is possible change only the nozzle, maintaining the calibration settings already established, may facilitate the adequacy of laboratories. For other hand, the flat fan nozzle can have open spraying angle of 80° or 110°. If the results to 110° are similar to 80° could be better to the test, since the spray height would be higher for the same settings. Thus, the objective this study is analyze the interference of pressure and spraying angle of nozzle in the results of ISO 17491-4.

Material and Methods
The spray cabin at Laboratory of the QUEPIA was used to conduct the testing. The spray cabin is in compliance with requirements specified at ISO 17491-4. A vertical spray boom with four nozzles spaced 0.45 m and 1.5 m far from the center of a turntable. The test uses water with dye and surfactant to achieve the specific surface tension. For method A, the standard specifies use of Hypro DC3/CR23 hollow cone nozzles with pressure of 300 kPa and flow rate of 0.47 ± 0.05 L min⁻¹. Based on preliminary tests, the XR8001 flat fan nozzle was selected for the study and one additional nozzle, XR11001, was added in order to enable the analysis of the effect of the spraying angle. All tests were carried out at 300 kPa. The measured flow rates were 0.45 L min⁻¹ for hollow cone and 0.40 L min⁻¹ for flat fan nozzles. A cotton plain weave fabric with 2.0 x 1.60 m was used as a sampler to collect the spray droplets. For quantitative analysis, 0.2 x 0.2 m squares were marked on the sampler with permanent marker prior to testing and the sampler was mounted on a rectangular frame placed in the center of turntable, perpendicular to the spray boom. Tests were conducted using a carrier...
containing methylene blue dye, 500 ppm of Cu+2, and surface tension adjusted to 52 ± 7.4 mN m⁻¹. Each test was conducted for 1 min with 3 replicates. After spraying, the fabric was carefully removed by three individuals and hung along the wall to dry overnight. Extreme care was taken in handling the tested samples. After dry, the 0.2 x 0.2 m squares were cut, coded to represent their position on the fabric, placed in plastic bags, and taken to the laboratory to quantify the Cu+2. In the laboratory, Cu+2 ion contained in the samples was extracted with 200 mL of HCl 0.2N solution. The amount was added, the bags was stirred for 30 s, the samples remained immersed in the solution for 12 hours, and then stirred again for 30 s. The extract was analyzed using atomic absorption spectrophotometry. The data for each test specimen was used to determine the spray distribution.

Results
The results using DC3/CR23 nozzle showed highest variability in spray distribution, with deposition decreasing with the height (Figure 1 A), similar result to the first study. The XR 11001 nozzle showed intermediate results and the best results was to XR 8001, where the proportion between percentage of deposition and height was more uniform. The increase in spraying angle did not result in higher depositions in the higher positions. This results can be explained by the kinetic energy of the droplets. Droplets with smaller kinetic energy are more impacted by the effect of gravity on the way to the target, increasing the losses. When analyzing the amount of product reaching the target (Figure 1 B), even with a flow rate around 11% lower, the deposition of XR 8001 was 56% higher than the DC3/CR 23. Studies about the interference of this increase in the pass/fail level must to be developed.

![Figure 3](imageurl) Variability of distribution patterns depending on the type spray nozzles.

Conclusion
The use the XR 8001 flat fan nozzles instead the DC3/CR23 hollow cone nozzle under the test conditions specified by ISO 17491-4, method A, can improve the results, even working with lower flow rate. However, additional works are needed to determine if the higher amount of liquid in the target has the potential to change the pass/fail level.

References:

ADDITIVE MANUFACTURING TECHNOLOGY FOR SMART TEXTILES

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Introduction
Additive manufacturing technology has potential in customization of large-scale protective textile material production. Fused Deposition Modelling (FDM) 3D printing technology is cost effective, material efficient, agile, several materials can be combined in one-step process and therefore can be utilized in integrating electronics into smart textiles [1]. The technique has the ability to provide complicated 3D geometries from work wear safety materials to create systems directly on fabric, which are not possible to design with traditional 2D printed methods. We have studied FDM technology for two different applications: printing of antennas and circuits using electro conductive filaments and encapsulating electronic components. FDM technology for encapsulation of electronics onto textile is fast and cost effective prototyping of the smart solutions for textile industry and also enables manufacturing of complex and conveniently customizable electronic structures as protective clothing for industrial work wear [1]. For further utilization of technology, washing resistance, wear resistance, flexibility and adhesion of the print on the textiles plays the most important role. The main goal of this work is to test properties of the prints on the textile substrate and checking physical properties of TPU encapsulated electronic system for protective clothing.

Experimental
For printing, Fused Deposition Modeling (FDM) a well-known extrusion based manufacturing 3D printing technique is involved [1]. The polymer filaments is heated and dispensed through the nozzle onto substrate. FDM parameters, including bed temperature, layer thickness, dispensing speed, etc. were investigated before the final good quality prints for further testing were obtained. For testing commercially available PLA (Polylactic Acid) based conventional, graphene filled, copper filled electro conductive, and as protective material flexible TPU (Thermoplastic Polyurethane) filaments were used for printing on textile. As protective coating on textile substrate, TPU is a well-known material which has superior physical properties of durable, flexibility, abrasion resistant, water resistant, chemical resistant, temperature resistance. Two types of textile fabrics were used: Fabric 1, 70% PE (Polyester) and 30% Cotton, and Fabric 2, 50% PA (Polyamide) and 50% cotton blends. Abrasion resistance is tested according to Martindale, using sand paper. For peeling/adhesion tests special sample arrangements were printed and the peeling performed using tensile tester. Flex tester was used to perform flexing tests. Tests were observed using freshly printed samples and also after several washing cycles at different temperatures according to standard (ISO 15797:2004). Encapsulation of electronics was performed printing the base layer of the TPU and PLA, placing electronic components and overprinting with the same polymer layer, design of 3D print is made based on the size of the electronic components encapsulated. TPU is used here for protective clothing especially for industrial work wear. Tests and the final product were designed to fulfill the industrial protective work wear standards. For the best printing
performance, the thickness of base layer of the encapsulation system was designed to make adjustment with the 0.3 mm thick RFID tag. Then, antenna was located on the TPU base layer when it reached 0.8 mm thickness. The top layer was printed up to 0.6 mm to build an encapsulation case. The top and bottom layer of TPU encapsulation provides the mechanical resistance and protective coating from the influence of environment, such as humidity, water, high temperature, chemicals etc.

Results
Tests performed using Fabric 1 and Fabric 2 have shown clear influence of textile composition on the properties of interest. Comprehensively, fabric 2 has behaved better than fabric 1. It has been found that nonconductive PLA and Graphene PLA provides better result in terms of abrasion resistance than conductive Copper PLA on both fabrics. 3D printed Copper PLA and flexible TPU on fabric 2 (50% PA, 50% cotton) provided best outcome for peeling tests before washing. One the other hand, best result for flexing resistance was found for Copper PLA on fabric 1(70% PE and 30% Cotton). Washing was performed at 40oC and 75oC temperatures. At 40oC, washing no significant change was found on any printed materials. PLA softens easily at about 80oC temperature. Washing of PLA up to 75oC lowered in abrasion resistance. In addition, Graphene PLA showed good abrasion resistance after washing at 750C. However, Copper PLA showed less abrasion resistance than Graphene PLA in both dry and after wash condition.

The availability of flexible TPU filament has made FDM 3D printed technology a candidate for integration of electronics on textile. Figure 1 shows 3D printed samples on textile substrate. 3D printed RFID antenna with conductive copper PLA (Figure 1 a), electro conductive circuit printed on textile (Figure 1 b), TPU encapsulated UHF RFID tag antenna on textile substrate by 3D printing technology (Figure 1 c). The Copper PLA printed antenna (Figure 1 a) shows maximum 5-meter reading range and encapsulated RFID tag antenna works explicitly same like the normal tag condition and maintains the reading range up to 6-8 meters. The tests for washing properties of printed TPU and tag antenna encapsulated with flexible TPU filament on textile were able to fulfill protective clothing standards.

![Figure 1. Different 3D printed samples on textile substrate: a) Copper PLA RFID antenna b) Copper PLA electro conductive circuit c) Encapsulated RFID tag antenna.](image)

Acknowledgement
The study is financed by EU ERDF though the INTERREG BSR programme, grant for SWW project (#R006).

Keywords: Protective clothing; 3D printing; PLA; Flexible TPU; RFID; Encapsulation.

References:
CHEMICAL PROTECTION AND DETECTION FOR COMPOSITE FUNCTIONAL FABRICS

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Introduction
Chemical protective clothing for emergency rescue is personal protective equipment that people involved in the rescue operations. Due to the extremely complicated rescue environment, the human body continuously contacts the intermittent splashes of particles in various sizes of aerosols, agent vapor and chemical liquids along with high temperature and heat radiation. Therefore, it is necessary to have excellent performances like resistance to chemical, mechanical and heat corrosion for high-grade clothing for chemical protection.

Experimental
In this work, chemical stable, superhydrophobic and limiting useful chemical protective fabric was developed for emergency rescue application. Firstly, Poly-m-phenyleneisophthalamide (mPIA) cloth was selected as a substrate, in which the chemical resistance, mechanical properties and thermal performances were investigated. Secondly, chemical resistant layer was investigated through hot process compounded with Polytetrafluoroethylene (PTFE). Superhydrophobic layer was achieved by coating with PTFE powder and nano-silica particles. Finally, the surface morphology, chemical protection detection and mechanical performances were analyzed. The composite fabric discussed in this paper has potential to be used for the chemical protective clothing.

Results
The results showed that the strength of MPIA was not affected by exposing to general acids, alkanes and organic solvents after 2 hour. Breaking strength and elongation of mPIA were about 0.54GPa, and 25%, respectively. Compared with the original fabric, the contact angle of composite fabric varied from completely infiltrating to 130°after the treatment of PTFE. When the composite fabric was coated with PTFE powder and nano-silica particles, the hydrophobicity of the composite fabric was significantly enhanced (CA158°, SA6) due to the role of low surface energy and rough nanostructures observed by SEM images. In addition, the composite fabric showed self-cleaning and high abrasion resistance. The results of FTIR indicated that the crosslinking between PTFE and SiO2 was built. The composite fabric was able to withstand H2SO4 (98w%) and NaOH (40w%) ASTM F1001 recommended.

Acknowledgement
This work was supported by National Key R&D Program of China (2016YFC0802802).

References:
SMART INTEGRATION OF PROTECTIVE CLOTHING AND PORTABLE CUTTING DEVICES FOR FOREST OPERATIONS

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Introduction
To improve labor productivity, it is necessary to ensure a safe and healthy working environment. However, especially in forestry, workers are always under the risk of hurt and severe accidents during forest operations [1]. The major reason is manual work in forests commonly associated with powered portable cutting devices such as chainsaw for tree felling, and bush cutter with circular saw for forest clearing (Photo 1).

Some "smart" functions would be integrated and installed on the protective clothing that they are wearing during forest operations for less risk and more safety without additional physical burden.

Protective clothing for forest workers
The EN381 series of standards cover the testing of chainsaw PPE. We indicate some examples of protective clothing such as trousers, chaps, gloves and shoes for forest workers (Photo 2) and give some explanations.

(Highly functionalized protective clothing.)
- Improvement of cutting resistance,
- Reduction of physical load due to thermal resistance,
- Weight reduction, Hi-Vis. in forest environment, etc.

Possibility and expectations
Wearing the Smart Integrated Protective Clothing not only improves body protection but also improves working efficiency, safety, health and productivity of forest workers.

(Physical data sensing and acquisition.)
- "Smart Textiles" or "E-textiles" technology,
- Working posture, Vital signs (heart rate, blood pressure, muscle action, etc.),
- Temperature and humidity inside clothes,

-- Information of working environment, worker’s body conditions and the productivity results of his forest operation are sensed and sent wireless to his smart-phone and analyzed by the AI automatically. Furthermore, AI will give him some feedbacks and assist him for his ideal next maneuver.

Keywords: Protective clothing; PPE; forestry; chainsaw; smart.
References:
SIMULATION OF THE HUMAN BODY THERMOPHYSIOLOGICAL RESPONSE USING THE HUTHEREG SOFTWARE

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Introduction
The HuTheReg software simulates the human body thermophysiological response when exposed to a wide range of thermal environments. With this tool, the optimization of sportive performance, the assessment of the thermal comfort during exposures to moderate thermal environments, the evaluation of the thermal stress and the risk of collapse in very hot or very cold situations, the evaluation of the thermal performance of usual suits or of protective clothing ensembles and as support for medical activities, among other scenarios, can indeed be considered and simulated in detail. In this paper, a sum-up of the development and validation stages of the HuTheReg software is presented.

The HutheReg software
The HuTheReg software (1) is composed by several modules, namely for the calculation of the human body thermophysiological response, the heat and water transport through clothing, the heat and mass exchange between the external surface of clothing (or skin) and the environment, the start and evolution of skin injuries (pain and burn) and the detection of specific incidents within the individual. Due to its interdependency, all modules run iteratively in each time step until a specific convergence criterion is reached.

The thermoregulation model represents the human body by 111 nodes, corresponding to 22 segments (face, scalp, neck, chest, abdomen, upper back, lower back, pelvis, left shoulder, right shoulder, left arm, right arm, left forearm, right forearm, left hand, right hand, left thigh, right thigh, left leg, right leg, left foot and right foot), each one formed by 5 layers (core, muscle, fat, skin and clothing) and the central blood compartment (the 111th node). The global algorithm is applied to each specific human body segment, but always considering its influence and interdependence with the global thermal state of the body. Thus, individual values of clothing characteristics must be specified for each one of the body segments.

With the HuTheReg software a significant variety of data can be obtained, both for the human body as a whole and for each of the segments, namely: (i) core, muscle, fat, skin and clothing temperatures; (ii) metabolism, heat stored and flux-rates of heat, of sweat, of water and of work; (iii) thermal comfort evaluation and indexes; (iv) detection of probable appearing of heat-related disorders; (v) skin pain, burn areas and corresponding degree; and (vi) a wide range of other thermophysiological parameters.

Results - validation
The evaluation, test and validation of the software ability to predict the human body thermophysiological behavior is performed by comparing the program predictions with experimental results from the scientific literature. For this purpose, a wide-range of conditions
was considered, which included different types of thermal environment (severe cold, cold, cool, neutral, warm, hot and very hot), of exposures (uniform, sudden change and cyclical), of exercise intensities (0.8 to 4 met) and of clothing (0 to 4 clo). The experimental results used for validation embraces core temperatures, average and local skin temperatures and mean body temperature as well as metabolic heat production and heat loss.

Figures 1 to 3 show a comparison between measured and predicted values where the experimental data represent averages for groups of individuals. The measured values of Figure 1 were obtained by Wyndham et al. (2) and Werner and Reents (3), of Figure 2 by Hardy and Stolwijk (4) and of Figure 3 by Kim et al. (5).

All validation tests have demonstrated a good prediction ability of the program which is a good indication of its capability to reproduce the human body thermoregulatory responses over the range of climatic conditions investigated.

Fig. 1. Comparison of measured (points) and predicted (lines) values for rectal, tympanic (exp.) / hypothalamus (calc.) and skin average temperatures and metabolism heat production, for 1 hour exposure with $T_{air} = T_{mr}$, $v_{air} = 0.2$ m/s, $RH_{air} = 50\%$, $I_{cl} = 0.1$ clo and $M = 0.8$ met.

Fig. 2. Measured (points) and predicted (lines) values of rectal and skin average temperatures and evaporation heat loss, for sudden ambient temperature changes from a hot environment of 43ºC to a cold environment of 17ºC and back again, with $T_{air} = T_{mr}$, $v_{air} = 0.2$ m/s, $RH_{air} = 30\%$, $I_{cl} = 0.1$ clo and $M = 1.0$ met.

Fig. 3. Measured (points) and predicted (lines) values of rectal, body average, skin average, fingers and toe temperatures for cyclic exposure to a warming environment (at 20ºC) for 20 minutes and an extremely cold one (at -25ºC) for 30 minutes, with $T_{air} = T_{mr}$, $v_{air} = 0.2$ m/s, $RH_{air} = 50\%$, $I_{cl} = 3.4$ clo and $M = 1.0$ met.

References:
INTERACTIVE SYSTEMS FOR EMERGENCY TEAMS

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Introduction
PROTACTICAL project aims at optimising and demonstrating an interactive Personal Protection Equipment (PPE), which holds promise to significantly improve firefighting and the response of emergency teams in other crisis situations, saving precious lives of both emergency personnel and civilians.

The PPE under development, not only is a traditional PPE, but it also monitors vital signs and the activity of users through the usage of special sensors built in the textiles. Parameter like the clothing microclimate, in particular environmental conditions such as temperature, humidity, CO, CO2; position with the capability to track and locate users; and the communications part that enable the transmission of all these data from the user and the operations command centre are just a few objectives of this new breed of intelligent PPEs.

Experimental
Having real time information about the individuals enable the operation command to have more information when it needs to decide on how to conduct the operation and how to protect their most valuable assets, the persons.

Successful demonstration of these features will be paramount to introduce an advanced PPE that will excel existing commercial solutions available worldwide.

Results
The project is led by Latino Confeções, which has been developing the PPE in partnership with some scientific partners since 2012. CRITICAL Software reinforces the consortium and its development efforts as a company specialised in the development of critical systems for security applications. The project further adds the National School of Firefighters as an associated external partner, enabling tests and real context demonstration to involve end users.
AN INTEGRATED NUMERICAL SIMULATOR FOR THE PREDICTION OF FIREFIGHTER’S HEAT STRAIN AND BURN INJURY

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Abstract
Fire has always been one of the catastrophic disasters that pose severe threats to human life and property. With the duty of fire fighting and rescuing trapped personnel in fire, firefighters have to encounter high-risk of burn injuries and deaths in spite of wearing thermal protective clothes. As a result, researchers have been paying great attention on studying thermal safety assessment of firefighters in recent years. With the rapid development of computer technology and numerical techniques, numerical estimation of firefighters’ heat strain and burn injuries has recently been a research focus, which would be of great advantage to substitute a virtual numerical experiment for a real experiment in terms of time, cost and safety.

In this study, an integrated numerical simulator for the estimation of firefighter’s heat strain and burn injury progress is proposed based on coupling an general-purpose Computational Fluid Dynamics (CFD) software (FLUENT), a multi-node (81-node) human thermal model [1], and heat and moisture transfer through multi-layer clothing and skin models [2, 3]. Firstly, FLUENT is used to simulate fire temperature distribution, and provide the transient temperature, the convective and radiative heat flux around the outer surface of the protective clothes. And then, the heat and moisture transfer through multi-layer clothing model is employed to estimate the skin temperature of firefighters, which is introduced as an indicator to evaluate the heat risk and then determine to whether call the 81-node human thermal model or the multi-layer skin model. If the skin temperature of firefighters is more than 40 °C, it is believed the high-risk of skin burn arises and the multi-layer skin model works, otherwise, the 81-node human thermal model is activated (see Figure 1). With the estimated core temperature, sweat loss, or inner skin temperature, finally the heat strain or burn injury of firefighters could be predicted. Furthermore a software with good pre-processing and post-processing function is developed based on the proposed coupled simulator (See Figure 2). This work could provide technical supports for thermal safety assessment of firefighters.
Acknowledgements
This work was supported by the National Key Research and Development Program of China (Grant No. 2016YFC0802801).

Keywords: Firefighter; Heat strain; Burn injury; Numerical model; Integrated simulator.

References:
SMART WORK WEAR – SMART HELMET

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Centria University of Applied Sciences hosts a digitalization project BILINE, in which the aim is to develop digital, IoT (Internet of Things) –solutions for the work safety of people in Kokkola Industrial Park (KIP), which is most significant concentration of the chemical industry in Northern Europe.

Smart helmet is a part of the smart work wear segment, in which BILINE and Centria’s Smart Work Wear –project collaborate closely. Smart helmet enables hands-free, two-way and automatic information flow between helmet and security systems.

The features of the smart helmet are determined according to the needs of the companies in KIP area. Needs were concluded by a survey conducted by BILINE-project. Companies of Kokkola industrial park represent a multitude of sectors and functions, which creates a challenging environment for product development. However, if the solution is satisfactory in this area, it is easily duplicated to other similar fields.

Smart helmet’s features are developed using existing IoT-products available in the market. The objective is to find use cases in industrial area and determine what are the technologies that can be effectively used in rough environments. The possible challenges are for example data transfer and product’s durability. Smart helmet will have features that promote safety at work, such as positioning, communication via video and/or sound, environment condition’s monitoring and alarms according to real-time data from the field.

A specific IoT-case can be found in two-way communication in industrial environment. The smart helmet’s case project uses mesh-network and modern IoT-network (Sigfox, LoRaWAN) to communicate between systems. In mesh-network Bluetooth 5.0’s new features, Bluetooth-Mesh is used to test data collection from the field among with Wirepas. They both enable large industrial scale mesh network to be set up in the challenging environment. Mesh-networks provide fail-proof solution for sending collected information from the field and sending information back to user.

Figure 1. Noedic semiconductors.

Acknowledgement
This study is financed by EU ERDF though the Finnish EAKR programme, grant for BILINE-project (A71949).
THE SPECIALIZED CLOTHING FOR THE FIREFIGHTERS –
ESTIMATION THE AIR TEMPERATURE FOR FEELING
THE THERMAL COMFORT

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Introduction
Work in a fire environment, under unnatural conditions, and the specificity of firefighters
working in open spaces, regardless of weather conditions, requires the use of suitable protective
clothing (1). In order to protect not only others, but also themselves, they must be fully
concentrated on their tasks so as not to make mistakes. The optimal conditions for such work
could be ensured by the so-called thermal comfort, characterized by the thermally neutral state
of the body. Comfort is influenced by two types of factors: environmental and individual.
Firefighters have no influence on environmental factors; they do work in the conditions which
they find on site. However, they can influence one of the individual factors, namely the
protective clothing.
Based on calculated thermal parameter of a firefighter’s special clothing, the range of air
temperature was estimated according to thermal comfort index – PMV (Predicted Mean Vote)
(2).

Experimental
The exemplary ensemble was the clothing used by polish firefighters US-03, without
underwear. The thermal parameter of clothing - the thermal insulation (3) was carried out with
thermal manikins of the Newton type manufactured by the Measurement Technology NW USA.
The tests were done in a climatic chamber where microclimate meters were used to monitor the
thermal conditions during the tests. Based on obtained results, the PMV index was calculated
for 4 different metabolic rates (2).

Results
The thermal insulations of the specialized clothing for the firefighters (Rct) were calculated and
obtained results were showed in Figure 1.

![Figure 1. The thermal insulation of clothing (Rct) used by polish firefighters US-03.](image-url)
Based on the obtained thermal insulation, the PMV index was estimated for the assessment of the thermal comfort. The ideal range of comfort is PMV between -0.5 and +0.5 (2). The extended comfort range is -1 <PMV <+1. Calculations were made for 4 classes of metabolic rate (rest - 65 W/m2, light work - 100 W/m2, moderate work 165 - W/m2, heavy work 230 W/m2) for assumptions: ta = tr, Va = 0.5 m/s , RH = 50%) (2). Obtained results were shown in figure 2.

![Figure 2. PMV index according to metabolic rate and air temperature.](image)

On this basis, it was found that at an air temperature equal 20 °C, only doing light work will allow the firefighter to feel the thermal comfort wearing a specialized clothing. At air temperature equal to 25 oC even light work causes feeling thermal discomfort. Above air temperature 25 oC, even resting will cause feeling the thermal discomfort.

**Summary**

The special clothing for firefighters is liked a barrier in the heat exchange between the user and the surrounding environment. Only in lower values of air temperature, the work performed by firemen could take place in conditions of feeling thermal comfort. In the case of the using a special clothing by firefighters, often estimated as comfortable ranges of air temperature are exceeded during the rescue operations.

It should be noticed that all calculation of PMV was done only for the insulation of special clothing for firefighters. In real conditions, the firefighter wears not only special clothes but also underwear, boots, helmets, gloves and heavy additional equipment. All of the mentioned elements increase the total thermal insulation value of the complete ensemble. It causes the air temperature, when firefighters feeling thermal comfort, will be even in lower.

For improving the feeling of thermal comfort during wearing the special clothing by firefighters, the thermal insulation of clothes should be reduced. New materials, which meet the protection conditions and do not invalid the heat transfer from the body to the surrounding environment, are the future in this kind of the protective clothes.

**Acknowledgement**

This study has been based on the results of a research task carried out within the scope of the forth stage of the National Programme “Improvement of safety and working conditions” partly supported in 2017–2019 — within the scope of research and development — by the Ministry of Science and Higher Education/National Centre for
Research and Development. The Central Institute for Labour Protection – National Research Institute is the Programme’s main co-ordinator.

**Keywords:** firefighters, clothes, thermal parameters, PMV, thermal comfort.

**References:**
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THE PREPARATION OF THREE-DIMENSIONAL TUBULAR FABRIC AND ITS COMPRESSION PROPERTIES

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Introduction
With the development of material standard of living, human beings’ demands for clothes are getting higher and higher. Especially in winter, some clumsy and bulky clothes can’t satisfy people’s desire for beauty. Multiple-functional clothing like warm, comfortable, and fashionable has become consumption mainstream of winter clothing. The down jacket is the best warm clothes in the present’s market. The structure of the down jacket is generally divided into the surface layer, the core layer and the inner layer. However, when the needle penetrates the fabric, the fiber is likely to be damaged and the fabric is deformed, which leads to drilling feathering problems. Zhong et al[1] put forward a kind of adaptive guide template, which could realize the weaving of complex composite preform without structural deformation. Sun et al[2] proposed a 3D circular weaving method which can produce 3D tubular fabric. The size and thickness of the tubular fabric could be changed easily. This paper makes a breakthrough in the structure design and forming technology in order to make one-time-shaped warm fabrics, which could solve the problem of feather drilling and improving duck's penetration resistance. In addition, by designing reasonable cavity size, feathers could be filled into the integral fabric smoothly and be distributed proportionally, achieving better effect of warm.

Experimental
In view of the shortcomings of the existing filling warm clothing structures[3, 4], on the basis of the existing weaving technology, this paper improves makes a breakthrough in the structure design and forming technology in order to make one-time-shaped warm fabrics with shape memory function. By shaping the fabric, it endows the fabric with excellent compression property and elastic resilience, and improves the static air content and stability of the flakes by increasing the porosity to improve the warmth retention. By the compression performance analysis, the key factors affecting the compression are obtained, including the diameter, arrangement density and bending stiffness of the monofilament. The research that the proportion of polyester monofilament and direction in fabric has effect on compression and elastic resilience of fabric.

Results
We weave three types of microcellular structure A, B, C on a loom. The three tubular fabrics were attributed with high hollow ratios by heat setting, that is A1, B1, C1, and constant load compression test method was used. The compression curves of the three tubular fabrics before and after heat setting were shown in Figure 1. According to the compression curve, the compression characteristics are extracted, including compression work, recovery work, hysteresis work, elastic resilience, and linearity. The results are shown in Table 1. Due to the
effect of monofilament and heat setting, it can be seen that the deformation of the fabric is different, and the compression property and the elastic resilience of the fabric is different.

![Stress-strain curves untreated and treated stereotyped three kinds of fabrics.](image)

**Figure 1.** Stress-strain curves untreated and treated stereotyped three kinds of fabrics.

<table>
<thead>
<tr>
<th>Sample NO.</th>
<th>compression index (%)</th>
<th>Compression work (mJ)</th>
<th>recovery work (mJ)</th>
<th>hysteresis work (mJ)</th>
<th>elastic resilience</th>
<th>Linearity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>1.374</td>
<td>0.876</td>
<td>0.498</td>
<td>64%</td>
<td>0.539</td>
</tr>
<tr>
<td>B</td>
<td>29</td>
<td>3.544</td>
<td>2.319</td>
<td>1.225</td>
<td>65%</td>
<td>1.397</td>
</tr>
<tr>
<td>C</td>
<td>28</td>
<td>1.973</td>
<td>1.091</td>
<td>0.882</td>
<td>55%</td>
<td>0.710</td>
</tr>
</tbody>
</table>

**Table 1.** Compression characteristics of three types of samples.

**Acknowledgement**
This work is supported by the National Key Research and Development Program of China (Grant No.2016YFC0802802), supported by “the Fundamental Research Funds for the Central Universities”, supported by Fok Ying Tung (huoyingdong) Education Foundation(151071), supported by Fujian Provincial Key Laboratory of Textiles Inspection Technology (Fujian Fiber Inspection Bureau) of China (2016-MXJ-02).

**References:**
PREPARATION AND CHARACTERIZATION OF PHASE CHANGE LAYER USED IN FIRE PROTECTIVE FABRICS

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Introduction
Firefighters usually encounter high heat flux exposures, which can cause severe burns. Fire protective clothing is a kind of special protective equipment for firefighters to ensure their safety and work efficiency. Multi-layer composite structure has been widely used in fire protective clothing to achieve more effective heat dissipation (1). PCM (phase change material) can absorb heat when it experiences a phase change, which can be from solid to liquid or from liquid to gas (2). The addition of PCM layer into a typical firefighting garment ensemble can mitigate heat damage and increase time for rescue.

Experimental
In consideration of safety, chemical stability, phase change temperature, latent heat and other factors, select mixed carbonates (Na2CO3, Li2CO3, K2CO3) and pentaerythritol as phase change materials in the fabric. The relevant parameters of ternary mixed carbonates and pentaerythritol are shown in the table 1. Use glass fiber mat as PCM embedded porous matrices for its porous structure and thermal stability (can be used under high temperature above 600℃). The relevant parameters of glass fiber mat are shown in the table 2. The PCM composite fabric uses a sandwich structure: 3-layer glass fiber mat and 2 different PCM layer. Test the thermal properties of the multilayer PCM composite fabrics and optimize the fabric composition.

Table 1. The relevant parameters of ternary mixed carbonates and pentaerythritol

<table>
<thead>
<tr>
<th>Material composition</th>
<th>Melting temperature(℃)</th>
<th>Heat of fusion(J/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na2CO3/Li2CO3/K2CO3</td>
<td>30/30/40</td>
<td>398</td>
</tr>
<tr>
<td>Pentaerythritol</td>
<td>---</td>
<td>187</td>
</tr>
</tbody>
</table>

Table 2. The specifications of nonwoven fabrics

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thickness(mm)</th>
<th>Weight(g/m²)</th>
<th>Density(g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2</td>
<td>0.517</td>
<td>53.55</td>
<td>0.104</td>
</tr>
</tbody>
</table>

Results
Multipile PCMs (mixed carbonate and pentaerythritol) are packaged in the composite fabric in the decreasing order of their melting temperature, which can make an almost constant temperature difference in the fabric under high temperature environment and achieve more efficient heat absorption. It is proved that the PCM composite fabric has good heat insulation and heat dissipation and the temperature can be reduced to around 200℃ in the back of the fabric for over 6 minutes under 550-600℃.

Acknowledgement
This study is supported by the National Key R&D Program of China (2016YFC0802802).

References:
IMPROVING THE STAB RESISTANCE OF FABRICS WITH HARD PARTICLES

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Abstract
With the occurrences of emergencies, more and more attention has been paid to personal protective equipment, especially the stab resistant clothing. How to avoid the harm from the sharp items such as dagger and bayonet was the key point of the research of anti prickly materials. There were various ways to prevent stabbing. In the early years, metal sheet and metal mesh were used to make burn-proof clothing, but they were heavy. With the development of the research, some new materials have been used in the burnproof clothing, such as high performance fibre, lightweight ceramics. Nowadays, most of the stab-resistant clothing were made of high performance fiber fabrics, they were light in weight and large in tensile strength. Therefore, the ultra-high molecular weight polyethylene fabric was used in this paper, and hard particles were coated on fabrics to prevent stabbing. Here, different ratio of rigid particles, curing agents and diluents to epoxy resin were compared on the fabric. The best ratio was elected by comparing stab-resistant performance of coated fabric. Then, different ratio of toughening agent was compared on the fabric. The best ratio of toughening agent was found. The coating liquid with different size of particle was used, and the influence of particle size on stab resistance was discussed. Finally, a best experimental scheme was found. Stab-resistant garment can be produced in this way. This lightweight stab-resistant suit was contributed to reducing the burden on armed police and security personnel.

Key words: stab resistant, fabrics, hard particles, coating.
WHY WE NEED SAFETY FOOTWEAR SPECIFICALLY FOR WOMEN?

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Lavoro

Introduction
As with fashion footwear, also in the field of professional footwear, women cannot be properly served if manufacturers limit themselves offering men's shoes with small sizes. Why? Because women do not just have different tastes, but mainly because women's feet have a different morphology. Hence, Lavoro has gone a step further to produce shoes specially designed for women. With the help of SPODOS-Foot Science Center, Lavoro realised it is possible to blend function, safety, design and comfort with the biomechanical knowledge of the female foot to make professional, trendy and more ergonomic footwear. The real challenge is educational and to practise a skill almost lost: knowing how to measure and fit a shoe to a woman's foot (a lot of footwear is based on general and outdated measurements and unsuitable for the diversity of gender and even regional feet).

Experimental
SPODOS-Foot Science Center studied foot shape and the anthropometric measures in young adult men (100) and young adult women (100). Three-dimensional foot shape data were collected through 3D imaging. Nineteen foot shape variables were measured, including girth (4 variables), length (4 variables), width (3 variables), height (7 variables), and angle (1 variable). A comparison of foot measured within the range of the common foot length (FL) categories indicated that women showed significantly smaller values of foot measures in width, height, and girth than men. Three foot types were classified, and distributions of different foot shapes within the same FL were found between women and men. Foot width, medial ball length, ball angle, and instep height showed significant differences among foot types in the same FL for both genders. There were differences in the foot shape between women and men, which should be considered in the design of professional footwear. SPODOS-Foot Science Center researches also indicates that shoes must protect the feet and facilitate full function. If not, they place the feet in unnatural positions, causing muscles to compensate via biomechanical imbalances. This can cause problems such as corns, toe deformities, spinal deformities, joint pain, and dysfunction of abdominal organs.

Results
Because women give more and more life to technical professions, Lavoro produces professional footwear suitable for the anatomy of the female foot. Its wide range of models for women gives Lavoro the status of specialist in women's professional footwear, a segment that has been reinforced regularly with new models, great versatility, accurate aesthetic sense and a lot of glamour! Women can now choose suitable professional shoes for their health's sake.

References:
PROTECTIVE CLOTHING FOR FIREFIGHTERS
COMPARATIVE REVIEW

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Introduction
There are several international standards that address the protection requirements for different kinds of protective clothing for firefighters. Depending on the conditions that can be found in different scenarios of intervention, risks may be different and so the protection needs. The main risk is usually a thermal one, but there are also other conditions that may require properties related to mechanical strength of the garments, biological protection, visibility, etc.

The aim of this poster is to offer a comparative view of the main requirements for the most commonly used kinds of protective clothing for firefighters, taking especially into account the new clothing for technical rescue. With such tool, it should be easier for end users to quickly find that differences in properties when selecting protective clothing for each of the interventions they need to undertake.

Methodology
By means of a study of the three standards that address the main kinds of protective clothing [1] [2] [3] used by firefighters, differences on thermal, mechanical, visibility and other requirements were analyzed. Also the marking required by each standard was studied in order to offer an easy explanation of the information supplied on it. Finally a collaboration with end users was carried out to improve the prospective of the document and make it match their needs as best as possible.

Results
In this work, a comparative review of the essential contents of the standards that have been studied is presented. For each of them, a brief explanation of the marking is given, what precedes a summary of the different protection requirements and the meaning of the performance levels that can be reached. Also a brief reference of the breathability and visibility characteristics of the garments is given. Performance requirements are then presented in a comparative table, in order to enable the user to quickly and easily classify the clothing by the needed criteria. Finally, some recommendations for the selection and use of each kind of clothing are offered, according to the applications included in the scope of the standards. As additional information to this, a useful document [4] on selection, use, care and maintenance of protective clothing against heat and flame, and some other standards related to PPE for firefighters, are referred.

Keywords: Protective clothing, firefighters, comparison, structure, wildland, rescue.

References:
4. CEN/TR 14560. Guidance for selection, use, care and maintenance of protective clothing against heat and flame

A provisional draft of the contents that will appear on the final version on the document can be found in the pages below.
COLDFIT: PROTECTIVE CLOTHING FOR COLD ENVIRONMENTS BASED ON THE BODY MAPPING OF USERS’ NEEDS

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Introduction
As a result of a PhD thesis carried out in the Department of Mechanical Engineering of the University of Coimbra dedicated to the assessment of working conditions in the cold (Oliveira, 2006), a representative sample of Portuguese workplaces was gathered (Oliveira et al, 2008). Despite being an academic work, it became very clear to both the supervisors and the PhD student that the knowledge acquired during the research should be made available to the society through an applied project. CITEVE, the Portuguese technological center of the textile industry immediately accepted this challenge and a consortium gathering four institutions was assembled (ADAI, CITEVE, TIPSAL and PARURBIS). The main outcome of this consortium consisted on the development of a newly protective ensemble, named ColdFIT, which was designed to fulfill specific features that were considered as very important to the safety and health of workers frequently exposed to extreme occupational thermal environments. Some of the main characteristics of the ColdFIT ensemble are presented in the present paper.

Development
The development of an insulating clothing suit started with the study of the working conditions and the activities performed, conducting inquiries to the workers in order to know their needs and the state of the art in terms of the existing products. The preparation of the prototype and its assessment (either in laboratorial and real environment) was performed in order to obtain a product with the CE-mark. Special emphasis was done to the thermal comfort and to the interactions between the environment, the human body, the activity and the clothing ensemble. For that, a protective clothing system composed by an inner layer (for moisture management), a middle layer (for thermal insulation) and an outer layer (for protection against the environment – wind, rain, liquids) was envisaged.

Experimental
In order to obtain the suitable thermal comfort, two main steps were adopted: the evaluation of the textile materials followed by the evaluation of the clothing ensemble. CITEVE performed several thermal resistance and water vapor resistance tests according to ISO 11092, using a skin model equipment (vd. Figure 1) in order to select the most suitable textile materials for each layer. Special attention was paid to the thermal resistance of middle layer and to the water vapor resistance of the inner layer and the outer layer due to its waterproofness.
The ADAI task consisted on the assessment of the clothing insulation of the ColdFIT ensemble, shown in Figure 2. For this purpose, two main devices were used: a climate chamber and a thermal manikin. The climate chamber, with several capabilities to control air temperature, humidity and air velocity in a wide range of conditions, has 4.5m×4.5m floor area and variable ceiling height. The thermal manikin was developed by P.T. Teknik, in Denmark, is divided into 16 individual parts and is articulated at the shoulders, hips, and knees by joints made of a circular cut in such a way that standing as well as sitting postures are quite natural.

**Results**

From an ergonomic perspective, the intermediate layer is the most relevant for mobility and ideally should be light, flexible and relatively bulky, whereby the results of the thermal resistance of the most promising materials were compared with their respective mass per unit surface area and thickness. In order to establish a compromise between thermal insulation and ergonomics, a material with a mass/surface area of approximately 100 g/m² was selected.

Regarding the clothing ensemble developed, when operating the thermal manikin with the constant skin temperature regulation mode (Tsk = 34 ºC) and considering the global calculation method, the result obtained for the total clothing insulation was equal to 2.63 clo.

**Figure 1.** Skin Model for thermal resistance and water vapor resistance tests.

**Figure 2.** Thermal manikin at the climate chamber dressed with the ColdFIT ensemble.

**Key words:** cold protective clothing; cold environments; user needs; thermal comfort.

**References:**

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