Nederlands Instituut Publieke Veiligheid

European Society of Protective Clothing

10th European Conference on Protective Clothing

Protection challenges in a changing world

9–12 May 2023 | Arnhem | The Netherlands

10th ECPC and NOKOBETEF 15

Protection challenges in a changing world

Proceedings of the 10th European Conference on Protective Clothing and NOKOBETEF 15 held in Arnhem, The Netherlands, May 9-12, 2023

Editors:
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About NIPV

The Netherlands Institute for Public Safety (NIPV) is the public research institute that acts as a link between safety regions, the Dutch government and various organisations which play a vital role in crisis management. NIPV supports these parties with research, education, support and information. NIPV is a centre of expertise with respect to high-level knowledge of crisis management, firefighting and fire prevention. In this way, NIPV contributes to a safer and more resilient country.

May 8, 2023

Foreword

The 10th European Conference on Protective Clothing is organized by Netherlands Institute for Public Safety (NIPV, Nederlands Instituut Publieke Veiligheid) in association with the European Society of Protective Clothing (ESPC).

ESPC was founded in 1997 in Denmark. Since 2000 the ESPC co-organizes every two-three years the European Conference on Protective Clothing (ECPC). However, there is a considerably longer history to the protective clothing conference that is bound to the tradition of research and information exchange in the Nordic countries on the subject. The NOrdisk KOrdineringsgruppe om BEskyttelseskläder som TEknisk Forebyggelsesmiddel (Nordic Coordination Group on Protective Clothing as a Technical Preventive Measure) was founded in 1984 and started then with the symposia on this topic.

The aim of the European Conference on Protective Clothing series is to promote research and cooperation in the area of personal protection. A functional and comfortable use of protective clothing is a key element for successful implementation of preventive and protective measures at the workplaces. This, 10th ECPC covers a broad spectrum of the subject protective clothing, and has turned into internationally qualified source of new, valuable and useful information for the advancement of the knowledge and the application of protective clothing. The conference has become a platform to disseminate, exchange and discuss the results of research, project developments and implementation programmes related to protective clothing, with a strong focus on user protection and well-being. Ergonomics is still a strong component of the conference within the new challenges related to climate change, pandemics and development of digital technology with new smart functions being an integrated part of textiles and modern PPE. Issues related to sustainability, durability of the products and consideration of full life cycle of PPE is high up on the agenda today. The changing business needs support from legislation and work with standardization has to keep up the pace so that the innovative and safe products can reach the market.

This conference acts as a forum for industries, public authorities and academic organizations – researchers, designers, manufacturers, purchasers, health and safety experts, human factors experts and procurement specialists and end-users to exchange and discuss research and project development for personal protective clothing (PPC) and equipment (PPE).

Arnhem in May 2023

Kalev Kuklane

The 10th European Conference on Protective Clothing: Protection challenges in a changing world

May 9 – May 12, 2023 | Arnhem | The Netherlands

Tuesday, May 9

11:00-13:00		ESPC board meeting at NIPV Arnhem
13:00-14:30		Arrival of conference attendees at NIPV Arnhem, registration, networking
14:30-15:15	Conference opening	Welcome speech by IJle Stelstra, General Director of NIPV Presentation of the sponsors, announcements

15:15-17:15	Session 1 Chairs: Ronald Heus and Ye-Sung Cho	Innovative protective products
15:15-16:15	**Keynote 1** Joo-Young Lee	Non-invasive wearable technologies to monitor heat strain

16:15-16:30		Coffee break

16:30-17:15		
	Daniela Zavec, Klaus Richter, Ella Lachmann, Irina Cherunova, Nikolai Kornev, Guobin Jia and Jonathan Plentz	ArTiShirt – workwear for cold and arctic temperatures
	Anna Dąbrowska, Monika Kobus, Piotr Sowiński, Łukasz Starzak and Bartosz Pękosławski	Integration of active clothing with personal cooling system within NGIoT architecture for improved comfort of construction workers
	Soraia Neves, Margarida Silva, João Ribeiro, Adriana Moreira, Patrícia Fernandes, Francisca Miranda, Gilda Santos, Rita Marques, João Miranda and João Campos	Combination of textiles and phase change materials for temperature management of a new firefighter protective vest - a numerical study

17:15		Return to the hotels (by a transfer bus)
20:00-21:30		Get-together at hotel Haarhuis (everybody goes on their own)

Wednesday, May 10

08:15-08:30		Arrival at NIPV, announcements
08:30-10:00	Session 2	Physiological impact of protective clothing and environment
	Chairs: Siyeon Kim and Edgar Garcia Torres	
	Keynote 2	
08:30-09:00	George Havenith, Josh Foster, James Smallcombe and Simon Hodder	Worker protection in a warming world – modelling the impact of climate and clothing on physical work capacity
	Jenni Kaisto, Sirkka Rissanen and Kirsi Jussila	Protection of face against cooling while using powered air purifying respirators in the cold
	Maria Stenkina, Ga-Young Lim, Yujean Ghim, Hyun-Soo Kim and Joo-Young Lee	Relationships between body morphological factors, core temperature, and heat extraction from the upper arm through a liquid cooling sleeve during cycling exercise
	Juhyun Moon, Siyeon Kim, Cho-Eun Lee, Yujean Ghim, Min-Seo Kim and Joo-Young Lee	Air-cooling vest is effective but not sufficient to alleviate physiological and perceptual heat strain of workers in a hot and humid environment
	Hyeshin Yoon	Physiological impacts and subjective comfort feelings by the amount of the total heat transfer through materials
10:00-10:30		Posters, exhibition and coffee break
10:30-12:00	Session 3	Symposium: digital human models and virtual ergonomics of PPE systems
	Chairs: Peter Bröde and md. Saiful Hoque	
(5 min)	Peter Bröde, Edith Classen, Jean Léonard, Ronald Heus and Kalev Kuklane	Digital human models and virtual ergonomics of PPE systems - a standardization perspective
	Paul Brasser	Scenario dependent optimizing the protective ability of PPE against its physiological burden
	Miriam Martinez Albert	Development of a new testing protocol to evaluate cooling systems
	Kalev Kuklane	Firefighter clothing database: preliminary modelling and exposure predictions
	Yordan Kyosev, Dominik Münks and Felix Kunzelmann	Possibilities for analysis of the motion comfort of protective clothing using high speed (4D) body scanning
	Timofey Golubev, Mark Hepokoski, Kevin Ward and Joel Coffel	Employing human thermal modelling to assess the effect of sweat accumulation on body temperatures
(10 min)		Panel discussion
12:00-13:00		Lunch

13:00-13:45	Session 4	Manikins and models
	Chairs: Kalev Kuklane and Lyda Kistemaker	
	Kamila Lunerova, Michal Masin, David Kaiser, Vladimira Fialova, Jan Pokorny, Barbora Rehak Kopeckova and Jan Fiser	Applicability of human thermophysiological model for prediction of thermal strain in PPE
	Seojin Lee, Sora Shin, Daeyoung Lim and Siyeon Kim	A comparison of thermal manikin test methods to assess cooling efficiency of cooling vests
	Kalev Kuklane, Koen Levels, Marijne de Weerd, Lennart Teunissen, Jakob Eggeling and Maurice Kemmeren	Comparison of clothing measurements on 2 manikins in the light of size and fit

13:45-14:15	Poster session	Main poster session with pitches (à 2 min)
	Tim van Harten, Kalev Kuklane, Ronald Heus and Hein Daanen	Ergonomic and performance differences between firefighter protective clothing systems
	Peter Bröde, Maren Claus, Doris Urlaub, Natalie Wolfsdorff and Carsten Watzl	Immune age: the feminine side of firemen?
	Eunju Lee, Yeonwoo Jung, Seung-wook Han and Siyeon Kim	3D virtual model construction of filter membrane and multilayered fabric structure of firefighters' particulate hoods to simulate particle loading behavior
	Siyeon Kim, Jungteak Oh and Seojin Lee	Degradation in tensile strength of flame-retardant textiles after exposure to high temperature and high humidity and suggestions for an accelerated hydrolysis test development
	Cho-Eun Lee, Juhyun Moon, Byung-Hee Hong, Joo-Young Lee, Yujean Ghim and Min-seo Kim	Cooling effects of a graphene oxide-coated sheet to alleviate exertional hyperthermia
	Mohammad Abu-Rous	The influence of cellulosic content on heat disspation in knits
	Seyoung Jeon and Hyojeong Lee	Development of digital garment clothing pressure distribution using 3D vector projection
	Anne Lamers	Exploring holistic body mapping and its application in a foul weather garment
	Anna Dąbrowska, Monika Kobus, Piotr Sowiński and Anita Jachowicz	Evaluation of health tracker's functionality in terms of its potential application to control the operation of protective clothing with cooling function
	Mark Gaskill and Robert Ormond	Assessment of fire investigator ensembles against chemical vapor and airborne particle infiltration
	Parris Tysinger, Bryan Ormond and Chandler Probert	Preliminary research to determine effectiveness of on-scene hose decontamination through comparison of different analysis techniques
14:15-14:45		Main poster session continues with exhibition and coffee break

14:45-16:15	Session 5	New materials and evaluation methods
	Chairs: Carlos Kuhlmann and Melissa Armistead	
	Bianca-Michaela Wölfling, Serge Lang and Edith Classen	Research and development of simplified ways to comprehensively evaluate thermophysiological comfort for complex PPE garment systems
	Jakob Eggeling, Róbert Toma and Kalev Kuklane	A new approach to estimate R_{et} values
	Ye-Sung Cho, Hee-Young Ju, Hyun-Soo Kim and Joo-Young Lee	Active heating shirts for workers in cold environments: which combination is more effective?
	Kiarash Arangdad	Sustainable alternatives to fluorinated water repellent protective fabrics
	Ana Rita Sousa, José Barbosa, O. Salomé G.P. Soares, João Ferreira, Ana Gonçalves, Gilda Santos, Augusta Silva, José Morgado, Patrícia Soares, Sergey A. Bunyaev, Gleb N. Kakazei, Cristina Freire, M. Fernando R. Pereira, Clara Pereira and André M. Pereira	Tailored materials for electromagnetic shielding textile application
	Anugrah Shaw, Thavy Staal, Marcelo Macedo, Hamilton Ramos and Sonja Sterman	User input for PPE for pesticide operators: a global framework for data collection

16:15-16:30		Coffee break
16:30-17:30		ESPC general assembly for all participants
17.30		Return to the hotels (by a transfer bus)

Thursday, May 11

Firefighter theme day

08:15-08:30		Arrival at NIPV
08:30-08:45		Opening of the day, welcome speech by Anton Slofstra, Safety Region Director and Fire Brigade Commander at VGGM Presentation of the sponsors, announcements

08:45-10:00	Session 6	Wildland firefighting and other operational conditions
	Chairs: Ricardo Weewer and Mark Gaskill	
08:45-09:15	**Keynote 3** Frank Pons, L. Landes, M Poulat, L. Joseph, Thierry Carret, Philippe Agopian	Health management of firefighters during natural wild fires. A global and integrated approach
	Jelmer Dam and Maurice Kemmeren	From urban structural firefighting to wildland-firefighting - a northwest European journey
	Maurice Kemmeren, Dirk Hagebölling, Kalev Kuklane and Ronald Heus	Higher standardised test performance of PPE materials does not automatically lead to higher safety
	Rijk van den Dikkenberg and Ricardo Weewer	When water goes up in smoke, experimental research into the effect of the 3D pulse method and the arc method on smoke cooling

10:00-10:30		Posters, exhibition and coffee break

10:30-12:00	Session 7	Ergonomic testing and human studies of clothing systems
	Chairs: George Havenith and Didem Kiryaman	
	Ronald Heus, Maurice Kemmeren, Lyda Kistemaker and Kalev Kuklane	A new test protocol for ergonomic evaluation of firefighters' protective clothing
	Eric Mol and Ronald Heus	(Psycho)physiological effects of wearing task specific protective clothing for wildland firefighters
	Meredith McQuerry and Cassandra Kwon	Evaluating female firefighter anthropometrics for improved mobility and design in personal protective clothing for the United States fire service
	Gilda Santos, André Barbosa and Ana Barros	Development of an obstacle course to evaluate the ergonomics of military prototypes
	Inga Dabolina, Valdis Cielens and Eva Lapkovska	Procedures for use of personal protective clothing, its ergonomics
	Aarti Solanki and Prof Dr. Pavan Godiawala	Knowledge mapping of ergonomic issues in firefighter's protective clothing: a bibliometric review

12.00		A group photo will be taken
12:00-13:00		Lunch

13:00-14:45	**Session 8**	**Evaluation of firefighter clothing materials performance**
	Chairs: Eric Mol and Bryan Ormond	
	Yulin Wu, Rui Li and <u>Guowen Song</u>	Polycyclic aromatic hydrocarbons (PAHs) simulation for standardized PPE contamination using a cone calorimeter
	<u>Vera De Glas</u>, Koen Van Deun and Riet Van Deun	Risk assessment report (RAR) of polycyclic aromatic hydrocarbons (PAHs) in firefighters and instructors
	<u>Bryan Ormond</u>, Arjunsing Girase, Nur-Us-Shafa Mazumder, Jingtian Lu and Andrew Hall	Transitioning the fire service to PFAS-free alternatives: trade-offs in exposure and performance
	<u>Thomas Verminck</u> and Nils Van de Vloed	Decontamination of EN469 fire gear as an essential part of the firefighters preventive measures against cancer
	<u>Md. Saiful Hoque</u> and Patricia Dolez	Aging of firefighter outer shell fabrics under accelerated conditions
	<u>Laura Munevar-Ortiz</u>, John A. Nychka and Patricia I. Dolez	Accelerated aging of moisture barriers used in firefighters' protective clothing
	<u>Bengi Kutlu</u> and Cansel Emir	Effects of tannic acid on flame retardant properties of jute and cotton

14:45-15:15		Posters, exhibition and coffee break

15:15-17:00	**Session 9**	**Special session: smart protection and innovative solutions in firefighter protection**
	Chairs: Rahel Krause and Gilda Santos	
(5 min)	Rahel Krause	Session introduction: European firefighter attitudes and needs for smart protection
	<u>Martin Camenzind</u>, Ivona Jerkovic, Elodie Morlec and Rene Michel Rossi	Adaptable thermal insulation for heat and flame protection on demand
	<u>Edgar Garcia Torres</u> and Emiel Denhartog	The effect of wind speed, ventilation, air layer thickness, and air permeability on heat flux in two-layer systems
	<u>Gilda Santos</u>, Soraia Neves, Margarida Silva, João M. Miranda, João B. L. Campos, J. Ribeiro, A. Moreira, P. Fernandes, F. Miranda and Rita Marques	Smart firefighters PPE: impact of phase change materials
	<u>Patricia Dolez</u>, Hyun-Joong Chung, Jane Batcheller, Chungyeon Cho, Diana Yehia, Lelin Zheng, Christina Braun, Reza Khalkhali, Zhitong Lin, Ashok Chhetry, Ankit Saha, Md. Saiful Hoque, Marwa Khemir and Nadeesha Samaraweera	Development of graphene-based end-of-life sensors for fire-protective fabrics
		Panel discussion

17:00		The bus leaves immediately after the sessions from NIPV to open air museum in Arnhem and brings the remaining conference participants to the hotels
17:00-21:30		Social event in open air museum - conference dinner (optional)

Friday, May 12

08:15-08:30		Arrival at NIPV, announcements

08:30-10:00	Session 10	Special session: sustainability in protective clothing and equipment
	Chairs: Henk Vanhoutte and Laura Munevar Ortiz	
	Keynote 4	
08:30-09:00	Edith Classen	How does circular economy influence PPE?
	Rahel Krause, Lilin Feng, Roshan Paul, Isa Bettermann, Thomas Gries, Ulrich Schwaneberg, Claus Hummelsheim and Lampros Kampas	Development of an alternative flame retardant finish for textiles for fire protection applications and an adapted finishing process
	Chloe Caux-Wetherell, Eric van Wely and Gokhan Duman	Nomex® Comfort with EcoForce™
	G M Nazmul Islam, Dave Kasper, Ted Parker, Jane Batcheller and Patricia Dolez	Recycling of post-consumer flame-resistant protective clothing
	Alexander Gstettner	Sustainability in flame resistant protective clothing with viscose FR fibers – the day after tomorrow

10:00-10:30		Posters, exhibition and coffee break

10:30-12:00	Session 11	Medical protection - innovation in production and respiratory protection
	Chairs: Frederik Goethals and Juhyun Moon	
	Peter Hazendonk and Frederik Goethals	Reservist project: Simulation of a rapidly deployment of an emergency hospital
	Gertrude Kignelman, Frederik Goethals, Silvia Pavlidou, Hannu Salmela, Anna Nardi and Marion Real	Reservist project: Blueprint for testing and certification of protective equipment in emergencies
	Bert Groenendaal, Joost Wille, Jan Bruneel, Christophe D'Halluin, Bernard Colson	Reservist project: Re-design of textile protective equipment for production via alternative lines in case of spiking demand times
	Selcen Kilinc-Balci, Zafer Kahveci, Christian Coby and Patrick Yorio	How do disinfecting wipes impact the barrier performance of protective clothing?
	Melissa Armistead, Anuja Dandekar, Marc Mathews and R. Bryan Ormond	Development of an animatronic headform test method to evaluate the efficacy of barrier face coverings
	Didem Kiryaman, Kaushik Nonavinakere Vinod, Emiel Den Hartog and Tiegang Fang	Filtration performance of cloth masks with different air permeability worn over a surgical mask

12:00-12:15		Short comfort break
12:15-12:45		Closing of the conference (awards, next conference)
12:45-13:45		Networking and farewell with lunch
13:45-...		Possibility to visit Hospitainer, a company from the Reservist project

Scientific Program Committee

Edith Claßen	Hohenstein Laboratories GmbH & Co	Germany
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Table of contents

Innovative protective products

Non-invasive wearable technologies to monitor heat strain

Joo-Young Lee

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Keywords
Physiological Strain Index (PSI), non-invasive parameter, heat strain, personal protective equipment (PPE)

Introduction

Workers, such as firefighters who should wear personal protective clothing even in hot environments, often suffer from excessive heat stress. Initially, a physiological strain index (PSI) was developed based on rectal temperature and heart rate to estimate heat strain of individuals (1). However, the difficulty of measuring rectal temperature in the field has hindered the further application of this index. Accordingly, the estimation of core temperature or body heat storage, itself, through non-invasive measurements has been proposed in numerous studies. However, there are still some technical limitations on the measurement in an actual field. The present study reviewed wearable technologies to monitor the heat strain of workers and suggested a modified model based on non-invasive wearable parameters for workers wearing personal protective equipment (PPE).

Table 1. List of the 13 previous studies that provided the datasets for the validity test.

Ref.(#)	Year	N	Air temp., Humidity	Experimental clothing condition (Total mass of PPE)	Exercise
2	2011	8	25°C, 32°C 50% RH	1) Control (Daily wear, 590 g), 2) Personal protective clothing (Level D, 787 g), 3) Personal protective clothing (Level D)+ Vinyl cover (1,245 g)	1) Rest (Sitting) 2) Exercise (2.7 km/h, 10%)
3	2012	8	22°C, 32°C 40% RH	1) Control (Fire protective clothing) 2) Type A protective clothing+ SCBA (heavy 11 kg) 3) Type B protective clothing+ SCBA (light 6.4 kg) 4) Type C protective clothing+ SCBA (light 6.4 kg)	6 km/h, 0% slope
4	2012	8	28°C 40% RH	1) Fire protective clothing (8.3 kg) 2) Daily clothes (Short t-shirt, short pants, 1 kg)	6 km/h, 0% slope
5	2022	19	32°C 60% RH	Fire protective clothing (8.3 kg)	1) 5.5 km/h 2) VO_{2max} 40%
6	2014	8	32°C 60% RH	1. Japanese Fire protective clothing (8.2 kg) 2. American Fire protective clothing (10.1 kg) 3. European Fire protective clothing (9.4 kg)	6 km/h, 0% slope
7	2014	8	28°C 40% RH	1. Control: Basic uniform (1.3 kg), 2. Full PPE (15.1 kg) 3. Full PPC +No SCBA (8 kg), 4. Full PPE +No Helmet (13.8 kg), 5. Full PPE +No Gloves (14.9 kg), 6. Full PPE +No Boots (13.1 kg), 7. Full PPE +No Jacket & Pants (11.8 kg) 8. Full PPE +No Helmet, boots, hood (11.6 kg)	5.5 km/h, 1% slope
8	2016	8	32.4°C 50% RH	Korean fire protective clothing (7.75 kg)	4.5 km/h, 1% slope
9	2015	12	32°C 43% RH	Korean fire protective clothing + SCBA (15 kg)	5 km/h, 0% slope
10	2023	8	32°C 50% RH 80% RH	1. Basic clothing: Long-sleeved shirt and long pants 2.Tyvek® 600 coverall with surged and over-taped seam 3. Tychem C (impermeable coverall, PU coated HDPE) 4. Nylon_long-sleeved jacket and long pants	Walking on a stepping box (25 step/min)
11	2017	8	32°C 70% RH	1. Japanese helmet (all-in-one) with firefighters' PPC 2. US hood and helmet with firefighters' PPC 3. Korean hood and helmet with firefighters' PPC	5 km/h, 0% slope
12	2020	8	30°C 50% RH	1. Control (no drink, 1,050 g) with firefighters' PPC 2. CO: Cooling only (1,340 g) with firefighters' PPC 3. DO: Drinking only (2,740 g) with firefighters' PPC 4. CD: Cooling and Drinking (6,525 g) with firefighters' PPC	5.5 km/h, 0% slope
13	2020	12	24°C 50% RH	1. Control (Only military uniform) 2. Type M water repelling coated military uniform 3. Type T water repelling coated military uniform	4 km/h, 4% slope
14	2021	8	25°C, 50% RH, 33°C, 70% RH	1. Medical gown with open back + surgical mask* 2. Medical gown + mask (KF94) 3. Tyvek 400 (Level D) + mask (KF94)* 4. Medical gown + Tyvek 400 (Level D) + mask (N95) 5. Tyvek 800J (Level C) + mask (N95)* 6. Tyvek 800J (Level C) + PAPR*	4 km/h, 0% slope

Methods

Firstly, the present study reviewed wearable technologies to monitor heat strain and extracted the most valid non-invasive parameters for workers wearing PPE. Using these parameters, the original PSI was modified. Secondly, data sets from 13 experiments (123 subjects, Table 1)(2~14), including the non-invasive parameters along with rectal temperature and heart rate, on PPE and heat strain, were collected. The validity of the modified models was tested using these 13 data sets. Thirdly, applicable conditions were suggested based on the clothing, environment, and activity level.

Results and discussion

Forehead, foot, and toe temperatures were chosen as the non-invasive parameters to monitor heat strain in workers wearing PPE in hot environments. The following modified PSI model using the non-invasive parameters was suggested: $5\,(Tskt - 33)\cdot(39.5 - 33)^{-1} + 5(HRt - HR0)\cdot(180 - HR0)^{-1}$, where Tskt represents forehead, foot, or toe temperature. After validating the modified model using the 13 data sets, the model was found to be highly correlated with the original PSI. In particular, models using foot or toe temperature exhibited greater validity than that derived using forehead temperature. However, there were limitations on the conditions under which the modified model using foot or toe temperature could be applied: 1) the environmental temperature must be above 30°C, 2) workers should wear personal protective equipment, including boots, and 3) a certain period of work with wearing PPE must have been performed.

Conclusions

These results can aid in the development of a heat strain monitoring system based on non-invasive parameters. This system can help to prevent heat-related illness by estimating the heat strain of workers wearing personal protective clothing in hot environments.

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ArTiShirt – workwear for cold and arctic temperatures

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Keywords
smart textiles, thermal protective clothing, thermal insulation layers, Aerogel nonwoven fabric insulation, metallized textiles

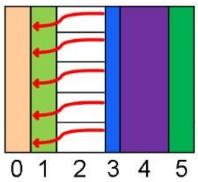
Introduction
Winter climate change and the retreat of the Arctic ice cover open up prospects for the development of Arctic routes and the expansion of raw material extraction, which require effective protection of people from the cold. Existing protective clothing uses thermally insulating components made of various materials. Necessary thermal insulation is achieved by the high thickness and results in high weight of the clothing.

The paper presents results of the project aiming at creation of a fundamentally new generation of protective clothing made of textile fibres based on aerogel technology. Aerogel has the lowest thermal conductivity of all solid materials. Due to its special physical properties, aerogel has hardly been used in clothing to date. In this project, an innovative highly efficient yet comfortable and wearable jacket, with a minimal thickness of insulation, will be created. In addition, a novel IR reflective layer based on a nickel coating will be integrated into the garment as an inner layer for thermal reflection (fabrication by Leibniz-IPHT Jena). This makes arctic temperatures and wind conditions more manageable.

Methods
In the novel insulation concept, the aerogel material represents the basic component for the insulating construction of the cold protection clothing. Such an aerogel fibre material is not available on the market and has to be newly developed. A polymer matrix is used as the basis for the thermoplastic spinning process with aerogel particles as the filling material. It is intended to place relatively thick monofilament polymer fibres with fibres of a diameter of 100 µm - 200 µm and a volume fraction of 25 %-30 % aerogel to achieve an exceptionally high thermal insulation value. The target U-value is 0.028 W/mK. The process has to be developed in such a way that a nonwoven formation and consolidation are possible and the wearing properties for the clothing meet the requirements. Since the density of the aerogel material is very low at approx. 0.003 kg/dm³, the high loading of the fibres does not have a negative impact.

The metallization of the textiles was performed as previously reported (1–4).

Further development will take place by simulating these novel material systems in terms of achieving the best parameters for thermal insulation and wind repellency in the clothing, taking into account the body properties by the research group of the University of Rostock. The main innovation is the further development of the calculation methods for determining the thermoregulation of humans in protective clothing. The creation of detailed models under the consideration of new aerogel materials and infrared reflective films is new and has not been done in this level of detail before. Overall, virtual engineering with variation of the aerogel materials is used to increase the functionality of the protective clothing under various conditions.



0	skin
1	2 mm undershirt
2	10 mm spacer fabric
3	0.02 mm IR-reflective layer
4	10-30 mm Aerogel nonwoven
5	1.5-2 mm outer jacket layer

Figure 1. Schematic structure with heat flow.

Results and discussion
The protective garment is to be constructed from five layers (see Figure1). The development of the aerogel fibre material (manufactured by TITK e.V., Rudolstadt, Germany) for insulation layer 4 has so far achieved a thermal conductivity of 0.042 W/mK for a fibre with a diameter of 80 µm and 0.039 W/mK for a fibre with a diameter of 145 µm at a fibre density of 116.38 kg/m³. In comparison, the measurement of a commercially available insulation nonwoven with the same fibre density showed a thermal conductivity of 0.046 W/mK. Finally, the production of a fibre with a diameter of 195 µm and a density of 153.97 kg/m³ resulted in a thermal conductivity of 0.032 W/mK. This is processed into an insulating nonwoven with the aid of 10 % binding fibre content.

The IR radiation generated by body heat emits through the undershirt and passes through an open, air-filled 3-D textile structure (layer 2) onto a textile surface coated with a thin nickel layer. Depending on the base material and the coating, a reflectance of 90% could be achieved. Thus, a significant part of body heat can be reflected.

The diagram (see Figure 2) illustrates the influence of the thickness of a polyester nonwoven and the emissivity on the skin temperature at an ambient temperature of -20 °C. If a nonwoven with a thickness of 15 mm is used for insulation layer 4, the transmittance of thermal radiation at a temperature of 33 °C at the skin surface should be 17 %. Due to the low thermal conductivity of aerogel, higher insulation can be achieved with an aerogel nonwoven.

In the further course of the project, the insulation of the total layer structure will be investigated in order to be able to draw conclusions not only on the insulation but also on the thermal resistance, the air permeability and the water permeability.

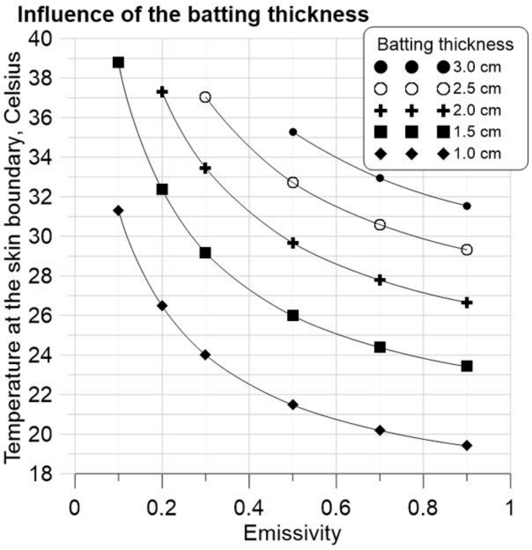


Figure 2. Influence of the thickness of a nonwoven and the emissivity on the skin temperature.

Conclusion

In the paper, the improvement of cold-protective clothing through a novel layer system consisting of a flexible aerogel nonwoven and an integrated infrared-reflecting textile layer is investigated. The aerogel nonwoven has a very low thermal conductivity compared to standardized insulation fleeces and can be used in thinner layers due to its high thermal insulation. The IR layer also ensures high reflection of body heat. Measurements of the individual layers to date have yielded promising results and suggest that the upcoming investigation of the total layer structure will confirm this. The thickness and weight of cold-protective clothing can be reduced by 15-20 % while still meeting current workwear standards.

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Integration of active clothing with personal cooling system within NGIoT architecture for improved comfort of construction workers

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Keywords

cooling clothing, thermoelectric effect, Peltier modules, IoT devices, wearables

Introduction

The problem of thermal load due to the exposure to a hot microclimate still persists for a significant number of workers and is expected to increase significantly with climate change (1). Construction workers are one of the groups experiencing this problem due to their work outdoors, often in full sun. Therefore, it is recommended for construction companies to provide solutions that will support workers' thermoregulation. A promising direction in this topic is the application of Peltier modules, which due to the temperature difference between their two sides can be used for either cooling or heating (2). The fact that the cooling intensity of Peltier modules can be regulated by means of electric power makes this technology possible to be integrated within smart work environments oriented towards an improved safety of workers. Therefore, a model of an active clothing with Peltier-based personal cooling system (PCS) and its integration within a Next Generation Internet of Things (NGIoT) architecture have been developed. The aim of this presentation is to discuss selected results of the PCS validation tests, as well as its expected functioning in the Smart Safety of Workers pilot within the ASSIST-IoT architecture (a H2020 project).

Methods

Cooling with the use of the PCS is based on the operation of 6 thermoelectric modules that have been integrated into the clothing. The developed PCS model allows the cooling intensity to be adjusted based on the temperature measured in the undergarment microclimate and the user's indications. The PCS model was tested with 6 users in laboratory conditions in terms of the impact of cooling on the user's thermal comfort. Laboratory tests were carried out at an ambient temperature of 25 °C and a relative humidity of 65% in two series: with and without cooling. The test procedure included performing physical activity in the form of walking on a treadmill at a speed of 5 km/h in three 15-minute series separated by 5-minute breaks. During the tests, local skin temperature was measured in places under and next to the Peltier modules, allowing registration of skin temperature and investigating its link with thermal comfort. In addition, during the tests, subjective evaluation of thermal sensations by participants was collected. Based on the research, a prototype of the PCS (Figure 1) was developed that will be integrated within ASSIST-IoT. The premise of PCS operation is the automatic adjustment of the cooling intensity by ASSIST-IoT based on indications regarding the temperature in the undergarment microclimate, heart rate measured with a wristband, and environmental conditions measured with a weather station, as well as including individual preferences of the user (learning capabilities).

Results

Laboratory utility tests have shown that the developed PCS model is able to reduce the local skin temperature by up to 2.7 °C when performing high physical activity and that the cooling effect is maintained throughout the entire study period. In addition, the research confirmed the subjective improvement of thermal sensations of about 1.5 points on a 5-point scale. The research allowed the identification of the issues that needed improvement and the introduction of the necessary structural changes in order to ensure greater freedom of movement, comfort of use and a higher efficiency of the cooling system. These conclusions were the basis for the PCS improvements and the development of its prototype.

A solution for integrating the PCS into the ASSIST-IoT architecture (3) was developed. The PCS communicates with Gateway Edge Nodes (GWEN) located on the construction site using the Ultra WideBand technology. In the virtualized environment provided by the GWEN, several ASSIST-IoT enablers and other components are deployed. The streams of data to and from the PCS are routed efficiently on the edge using the Edge Data Broker enabler. The data from the PCS are annotated semantically to enable the interoperability between devices (including the wristband measuring the heart rate, the PCS, and the weather station), using the Semantic Annotation enabler. Collected measurements are used by an artificial intelligence (AI) solution to instruct the PCS about the adequate cooling power at a given moment. Similarly, user's preferences are remembered by the AI and taken into account in future decisions. To preserve the user's privacy, care is taken to process their private data only on the edge and discard it afterwards.

Figure 1. PCS prototype.

Discussion and Conclusions

The tests of the PCS model showed that the developed solution can effectively reduce the local skin temperature and positively affect the feeling of thermal comfort. After its integration within ASSIST-IoT, the developed PCS prototype will allow the automation of the system's operation and thus very little user interaction will be required. The proposed architecture takes special care to preserve user's privacy while using data from several sources to adjust the cooling power in real time. After integration, the PCS prototype will be tested at a construction site during the summer season to verify the functionality and usability of the system in semi-real conditions in ASSIST-IoT's validation phase.

Acknowledgments

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> Phase V of the National Programme "Improvement of safety and working conditions" in the years 2020–2022 supported from the resources of the National Centre for Research and Development. task no. III.PB.09, entitled "Development of the protective clothing with an active cooling function based on the thermoelectric effect (Peltier modules)". The Central Institute for Labour Protection—National Research Institute is the Programme's main coordinator.

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Combination of textiles and phase change materials for temperature management of a new firefighter protective vest – a numerical study

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Keywords
firefighter protective clothing, multilayer system, phase change materials, transient behaviour, thermal performance, numerical simulation

Introduction
Advanced materials have come into sight to increase the thermal protection given by firefighter protective clothing (FPC), either with embedded wearable electronics to monitor environmental/physiological parameters in real time or with integrated phase change materials (PCMs) to minimize the heat stress felt by the firefighter. The thermal protective efficiency of the latter (FPC with integrated PCMs) has been demonstrated in theoretical studies (1,2). Additionally, Santos et al. (3) recently studied a prototype of a PCM vest to be worn over the conventional FPC. The authors proposed a new vest composed of a structure with a removable matrix of individual PCM pouches. This smart clothing system is promising; however, as a drawback, the non-uniform distribution of the vest properties can trigger the appearance of hot spots between the pouches, which can jeopardize the vest thermal performance. With this in mind, a bi-dimensional numerical simulation model was developed to study the effect of different combinations of materials (e.g., textiles and PCMs) for temperature management and uniformity inside the protective vest.

Methodology
The heat transfer across the several domains of the PCM vest (i.e., air gaps, textiles, insulation material, and PCM pouches) was studied numerically using a FEM-based approach. The vest has a matrix with a repetition of units ((3), Figure 1a). Therefore, the simulation domain considers only a cross-section across of one unit covering a wildland firefighting jacket, as shown in Figure 1b. The model considers the PCM phase change, the radiation inside the air gaps, and the heat conduction through the several domains. The model enables the prediction of the thermal exchanges between the PCM vest and the surrounding environment (by natural convection and radiation), providing information about the multilayer assembly's heat distribution and transient behaviour during the exposure to a radiant heat flux (i.e., 11.6 kW·m^{-2}). The time the PCM is fully melted was used as the test stop criteria.

The effects of the properties of highly conductive textile materials (with different thermal conductivities and thicknesses), as well as their best position inside the vest (e.g., covering the entire PCM pouch or only between pouches), were studied to ensure an optimum uniform distribution of temperature along the firefighter's skin. Several configurations of the vest matrix were also studied, considering different amounts of pouches and types of PCMs incorporated in the textile matrix.

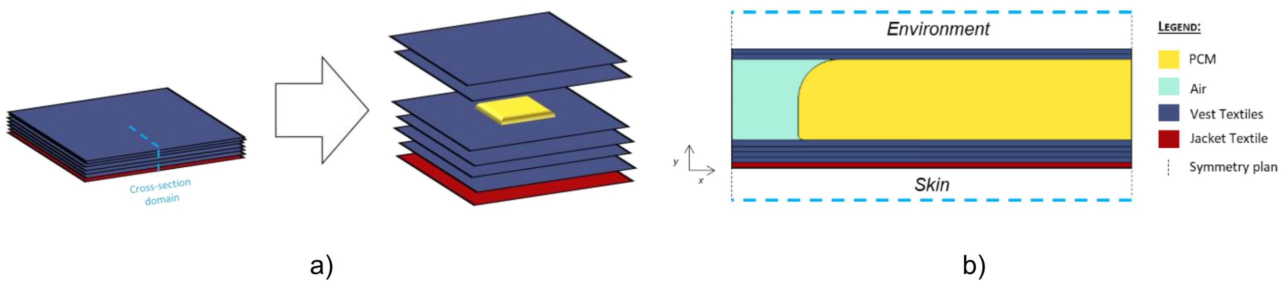

Figure 1. a) Example of one unit of the PCM vest and corresponding layers covering a wildland firefighting jacket; b) Simulation domain.

Results and discussion

The obtained temperature profiles compare favorably with data from experimental measurements with PCM pouches.

For the several configurations of the vest, it was observed that a reasonable homogeneous temperature distribution along the firefighter's skin is obtained with textile materials with thermal conductivities lower than 34 W/m/K. Furthermore, it is advantageous that the mentioned textile layer covers the entire vest in direct contact with the PCM pouches. The relative position of the high-conductivity textiles compared to the PCM pouch is also critical. For example, as shown in Figure 2, the difference between the hot and cold spot decreases from configuration a) to b), particularly for thick conductive layers.

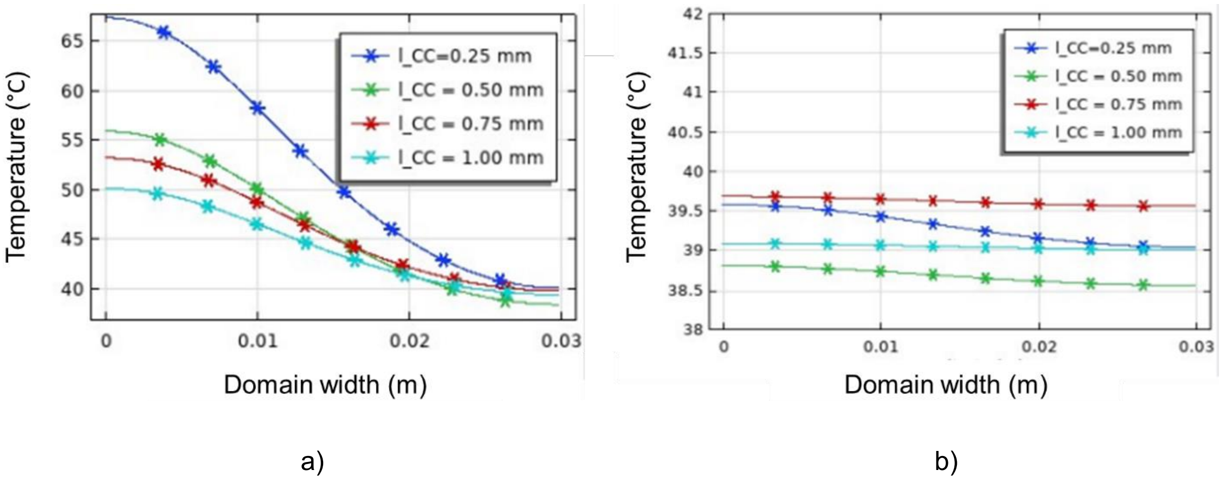

Figure 2. Skin temperature distribution obtained with different thicknesses of a conductive textile layer (l_CC) located in different zones of the vest matrix: a) covering the entire PCM pouch or b) underneath the PCM pouch.

Conclusions

The thermal performance of a PCM vest was numerically studied. This study demonstrated the advantage of integrating highly conductive textile materials in different PCM vest matrixes to ensure a homogeneous skin temperature distribution without jeopardizing the vest thermal protective performance.

Funding

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Physiological impact of protective clothing and environment

Worker protection in a warming world – modelling the impact of climate and clothing on physical work capacity

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Keywords
worker, climate, clothing, performance, protection

Introduction

Climate change is already affecting the workforce in many countries. In order to estimate the impact of climate change on the global economy, and to understand how to keep workers safe, information is needed on how climate affects the workers' output. This talk will report on the Loughborough contribution to the EU Horizon 2020 HEAT-SHIELD project (https://www.heat-shield.eu/), dealing with estimation/modelling of the worker output in a warming climate.

Methods

A limited amount of data was available so far on quantification of work output in hot climates. Several studies looked at productivity in offices (1), showing a U-shaped curve for productivity losses against temperature, but only few looked at productivity in physical work. Notably Wyndham (2) studied Bantu labourers in South African gold mines, and investigated how productivity (shovelling rocks into train carts) was affected when the temperature/humidity increased. Wyndham warns in the original paper, that results were specific to highly acclimatised Bantu workers only. Sahu et al. (3) looked at the productivity of rice harvesters, when the working days got hotter. In both studies results were compared to productivity in an already warm climate, so no data were applicable to milder heating conditions. Hence, as these data had severe limitations, and tend to be applicable only to the specific activity, we developed a new generic study protocol to look at productivity in the heat (4-7). This looked at productivity in work, paced based on cardiovascular load. As other studies (e.g. (8)) showed that workers tend to pace their work below a heart rate of 130, and as following WHO guidance this value is the separation between moderate and hard work, it was hypothesised that testing work productivity at a cardiovascular strain associated with a heart rate of 130 bpm, would reflect the maximal work output that could be expected of workers in different climatic conditions. I.e., the protocol aimed at measuring the amount of work the body can generate at a fixed, maximally acceptable cardiovascular strain (130 $b \cdot min^{-1}$) across a broad spectrum of air temperature (Ta, 15–50 °C) and relative humidity (20–80 %), wind (0 and 4 m/s) and solar radiation (0 to 800 W/m2). The spectrum of environmental conditions represents mild exposures to more extreme levels that extend into future worst-case greenhouse gas emission scenarios Work was done semi-nude and in work coveralls.

Results and discussion

The data obtained in over 900 individual heat exposures, allowed creation of an empirical model of worker productivity in relation to climatic stress, discriminating between the effects of temperature, humidity, wind and thermal/solar radiation. Data/models were developed for different heat stress indices, with the main being WBGT and UTCI. Comparison of the different heat stress indices (humidex, heat index PET, PET*, Oxford Index, PT, SET, AT, WBGT, UTCI) showed that WBGT and UTCI worked best, while in wind only UTCI was able to explain the physiological impact.

Clothing (shorts versus shorts/Tshirt/coverall) did not have a big impact on the outcome, but did show the detrimental effect at lower heat stress and the protective effect at very high air temperatures/radiation levels. Limitations of these models need to be considered. Due to the generic work performed (treadmill walking), specific features (e.g. skill required) of the many possible tasks may not be fully captured. The testing population existed of young males only, though it is assumed that when one considers the individual's maximal work capacity, it may also be applicable to older people or females. This needs to be validated.
In this presentation we will provide an overview of the project and its outcomes and highlight the impact of the protective clothing on the results. We will also discuss limitations and future work.

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Protection of face against cooling while using powered air purifying respirators in the cold

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Keywords
facial cooling, cold protection, respiratory protection, powered air purifying respirator, PPE

Introduction
Respiratory protective devices (RPDs) are required to use outdoors in several professions, for example in industrial work and mining. Powered air purifying respirators (PAPRs) provide a high level of protection with low breathing resistance due to the positive pressure from air supply. Problems in the use are, however, observed when PAPRs are used in cold conditions. Continuous cold air flow into the user's face lowers skin temperature rapidly. Skin temperature decrement to lower than 15°C cause uncomfortable sensations and even pain (1). In this study facial cooling and protection of face from cold while using loose-fitting PAPRs in cold environment were studied. Aim of the study was to compare different types of facial cold protections used together with PAPR.

Methodology
Skin temperature of forehead, cheek, nose and chin were measured from five test subjects (3 females and 2 males, mean age 45.6 ± 12.6 years) while they wore a PAPR integrated with a helmet at an ambient temperature of -10°C and with the wind speed of 2 m/s. Mean face skin temperature (MFST) was calculated as the average of forehead, cheek, nose and chin skin temperatures. Subjects performed a 50-min trial that consisted of 10 min rest, 25 min walking at a rate of 4 km/h and 15 min rest. Facial as well as whole-body thermal sensations were recorded at the end of each task. Merino wool balaclava (WO 75%, PP 22%, PA 3%), windproof balaclava (PES 96%, EL 4%) and developed FIOH Face Protection against Cold (figure 1) were used to protect the face from cooling. The first two were commercial products covering the head and face, while FIOH Face Protection against Cold was own design and covered only the facial area. Thickness, air permeability and thermal insulation of facial cold protections were measured (table 1).

Figure 1. FIOH Face Protection against Cold together with PAPR.

Table 1. Properties of the tested materials.

Cold protection	Thickness (mm)	Air permeability (mm/s)	Thermal insulation (m^2K/W)
Merino wool balaclava	1.0	1202	0.089
Windproof balaclava	1.6	5.6	0.091
FIOH Face Protection against Cold	2.3	504	0.078

Results
At the end of the test, MFST lowered to 14.95 ± 0.86 °C while using PAPR in the ambient temperature of -10°C without cold protection (figure 2). Cooling of the face during the first 10 min of the test was 0.3 – 0.4 °C/min faster without facial cold protection (1.1 °C/min) than while wearing protection (0.7 – 0.8 °C/min). At the end of the test, MFST was 18.09 ± 3.89 °C with merino wool balaclava, 19.43 ± 2.37 °C with windproof balaclava and 19.18 ± 1.25 °C with FIOH Face Protection against Cold. MFST at the end of the test was approximately 4°C higher while facial cold protection was worn underneath the facepiece. No significant

differences were found in MFST between the different types of facial cold protections. At the end of the test, face was most often perceived ''cool'' and ''cold'' without protection and ''slightly cold'' and ''neutral'' with facial cold protection.

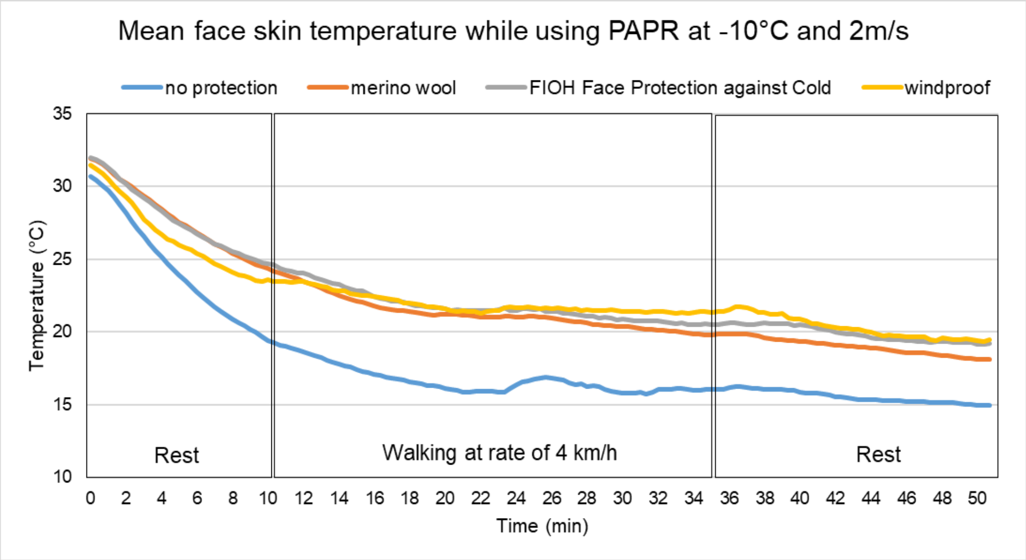

Figure 2. Mean face skin temperature while using PAPR in cold with and without facial cold protection.

Discussion

Facial cooling was reduced while cold protection was worn under the PAPR. In this study, cold protection provided by the facial cold protective equipment was at the same level regardless the tested equipment varied by model, thickness, air permeability and by the fabric content. Nonetheless, model of the facial cold protection must be considered when also other personal protective equipment (PPE) is worn around the head area. Especially, use of earmuffs together with balaclava is not recommendable due to the lowered efficiency of hearing protection. Presented FIOH Face Protection against Cold do not cover ears and thus is compatible with earmuffs.

Conclusions

Severe facial cooling was observed while wearing PAPRs in the cold. Facial cold protections effectively protect the facial skin from cooling. It is however notable that facial cold protection can only be used together with loose-fitting PAPRs and compatibility with other PPE must be ensured before use.

Acknowledgements

The study was financially supported by The Finnish Work Environment Fund.

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Relationships between body morphological factors, core temperature, and heat extraction from the upper arm through a liquid cooling sleeve during cycling exercise

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Keywords

upper arm, liquid cooling garment, heat extraction, arm surface area, body mass index, skin temperature

Introduction

The upper arm region's peripheral temperature regulation and heat flow has received relatively less attention than that of the forearms or hands. Since corona pandemic 2019, concerns over body temperature prediction using non-invasive parameters have increased (1). In addition, studies on wearable technologies such as smart watches, shirts, and arm bands to monitor vital signs of workers and athletes have increased (2). Such research are intimately connected to liquid cooling garments (LCGs), which are the main tool for regulating astronauts' body temperature during their extravehicular activities in space (3). However, more improvements on local design and functions of the LCGs are required to monitor real-time vital signs and provide individually-optimized LCGs for each astronaut (4). A couple of studies reported that core body temperature is closely related to the temperature of the upper arms than the periphery (5). In this regard, we hypothesized that the heat extraction from the upper arm would be significantly related to overall body morphological factors as well as to core body temperature during exercise.

Methods

A total of 8 males and 11 females (Table 1) participated in a trial of 60-min rest followed by cycling exercise at 50 rpm for 60 min (50 ~ 55 W for males and 40 ~ 45 W for females) in a climate chamber (25 ± 0.2°C, 50 ± 4%RH). Subjects wore a liquid cooling sleeve over the left upper arm (Figure 1).

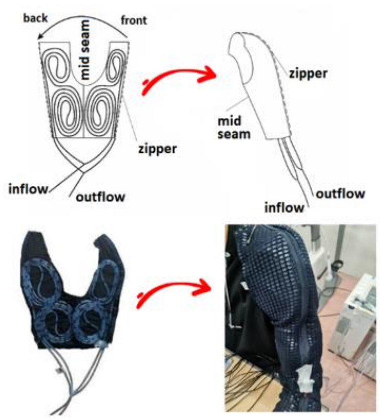

Figure 1. Liquid cooling sleeve.

Tube length within the sleeves was 657 ± 82 cm (various sizes provided) and water flow rate was 38.7 ± 19 L·h^{-1} (645 ml/min). Water inflow and outflow temperatures were recorded every 5 s using a data logger (LT-8A, Gram Corporation, Japan). The water inflow temperature was maintained at 24.0 ± 0.3°C. Heat extraction (HE) through the sleeve was calculated using the water inflow and outflow temperature and water flow rate (6). Upper arm skin temperature inside the cooling sleeve (T_{arm}) and rectal temperature (T_{re}) were recorded every 1 min. The surface area of the upper arm was measured using the alginate method (7) and the volume of the upper arm was measured using an arm volumeter (AliMed, USA). The overall body morphological parameters (body weight, body mass index [BMI], %total body fat [%BF], total body water, skeletal muscle mass) were obtained using bioelectric impedance analysis (InBody 970, Korea).

Table 1. Anthropometric and morphological characteristics of male and female subjects (*UA: upper arm).

Group	N	Age (y)	Height (cm)	Body weight (kg)	Body mass index (BMI) (kg/m²)	Total body fat (%BF)	UA* surface area (cm²)	UA volume (mL)	UA circumfer-ence (cm)
Female	11	24 ± 2	160.5 ± 5.6	59.9 ± 6.5	23.3 ± 2.6	31.8 ± 3.9	552 ± 74	1,100 ± 300	29.2 ± 3.3
Male	8	24 ± 2	174.2 ± 6.1	78.5 ± 13.6	25.2 ± 2.5	22.7 ± 6.9	639 ± 90	1,500 ± 300	33.8 ± 3.4
Total	19	24 ± 2	167.0 ± 9.2	68.7 ±14.0	24.2 ± 2.7	27.5 ± 7.2	589 ± 90	2,600 ± 700	31.1 ± 4.0

Results and discussion

Significant relationships were found between BMI and the upper arm morphological parameters. The greater BMI the greater upper arm volume (r = 0.66, $P < 0.01$), upper arm surface area (r=0.67, $P < 0.05$), and girth of the upper arm (r = 0.863, $P < 0.001$). Heat extraction (HE) from the upper arm was 37.6 ± 22.5 kcal·h^{-1} at rest and 38.0 ± 20.5 kcal·h^{-1} during cycling, with no significant difference. For the female group, heat extraction was 32.2 ± 24.9 W (at rest) and 28.4 ± 19.0 W (during cycling), which were less than the male group: 45.1 ± 17.5 W (at rest) and 51.2 ± 14.8 W (during cycling). The female group's HE corresponded to 71% (rest) and 55% (cycling) of males' HE. The rest value could be attributed to the sex differences in the arm volume, but the exercise value was greater than the sex differences in the surface area or volume of the upper arm. There were negative relationships between HE and total body fat during cycling ($P < 0.05$, Figure 2A) but not at rest, whereas no relationship between HE and upper-arm surface area was found for either males or females (Figure 2B). We found a negative relationship between HE and the volume of the upper arm for the male group only during cycling ($P < 0.05$, Figure 2C). Rectal temperature at the end of exercise was 37.3 ± 0.3°C (females) and 37.3 ± 0.2°C (males). There was no relationship between HE from the upper arm and rectal temperature during cycling and rest.

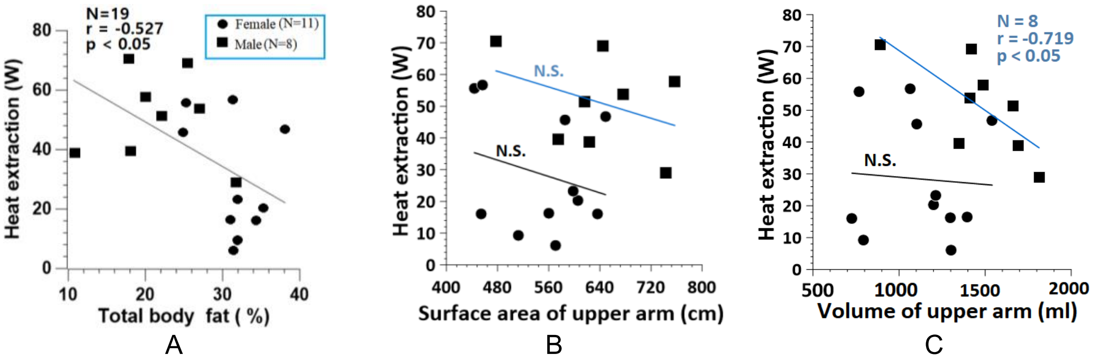

Figure 2. Relationships between heat extraction and total body fat (A), upper-arm surface area (B), and volume of the upper arm (C) for males and females during cycling at 40~55 W with 50 rpm.

Conclusions

Local heat extraction from the upper arm during cycling exercise was greater for individuals with lower total body fat (%) and smaller arm volume. The relationships were more notable for males than females. That is, thin males with slim or smaller arms had greater heat loss from the upper arms during cycling exercise, which could be estimated by the overall total body fat. These results can be applied to wearable technologies to predict local body heat flow using on non-invasive parameters and morphological factors. However, dynamic exercise that are mobilizes upper arm muscles may cause different results. Further studies on the thermoregulatory role of the upper arms in cold and hot environments are required as well as the studies based on the different modes of exercise.

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Air-cooling vest is effective but not sufficient to alleviate physiological and perceptual heat strain of workers in a hot and humid environment

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Keywords
agricultural worker, air-cooling vest, heat stress, pesticide protective clothing, hot and humid environment

Introduction
Recently, various types of cooling vests based on PCM, liquid-cooling, and air-cooling have been developed to protect occupational workers exposed to excessive heat stress (1). However, previous studies focusing on cooling vests for agricultural workers are limited. This is especially true for Korea, which has hot and humid summers; Korean agricultural workers tend to not wear full pesticide protective clothing because of the thermal burden (2). Unlike PCM or liquid-cooling vests, air-cooling vests are battery operated, which makes them more convenient and more useful for a longer period. The purpose of the present study was to investigate the effectiveness of an active air-cooling vest in hot and humid environments through human wear trials with partial pesticide protective clothing.

Methods
Nine young Korean males (24.6 ± 3.6 y, 172.9 ± 3.3 cm, 67.6 ± 9.3 kg, and 1.84 ± 0.12 m^2) participated in this study. All subjects were dressed in summer work wear of agricultural workers: long-sleeved t-shirts, undershorts, pesticide protective work pants, a cap, gloves, and socks. Two experimental conditions were compared: (1) No cooling but wear an active air-cooling vest (1,327 g in vest mass, Outer shell: 93% Meta-Aramid + 5% Para-Aramid + 2% Antistatic, Distance mesh: 100% Polyester, Lining: 100% Polyamid, rechargeable; Teijin, Japan and Netherlands) and (2) Air-cooling with the air-cooling vest. When turning on the cooling button of the vest, air was distributed over the entire chest and back regions through the minute holes in the vest lining. A trial consisted of two bouts of exercise with breaks to simulate work-rest schedule of agricultural workers (Fig. 1). All trials were conducted in a climate chamber with an air temperature of 33^{o}C, 65%RH, and insensible air flow. Rectal temperature, skin temperatures (10 points), total body mass, thermal sensation (9-point categorical scale; -4 very cold ~ 4 very hot), and thermal comfort (7-point categorical scale; -3 very uncomfortable ~ 3 very comfortable) were measured for 90 min. Rectal and skin temperatures were recorded every 5 s and subjective responses were obtained every 10 min. Total sweat rate was estimated through the changes in body mass (Satorius, Germany). Mean skin temperature was calculated using a surface area-weighted equation based on Hardy & DuBois 7-point formula (3). All data were expressed as mean ± SD. A paired t-test and a Wilcoxon test was conducted to test differences between the two conditions and a significance was set at $P < 0.05$.

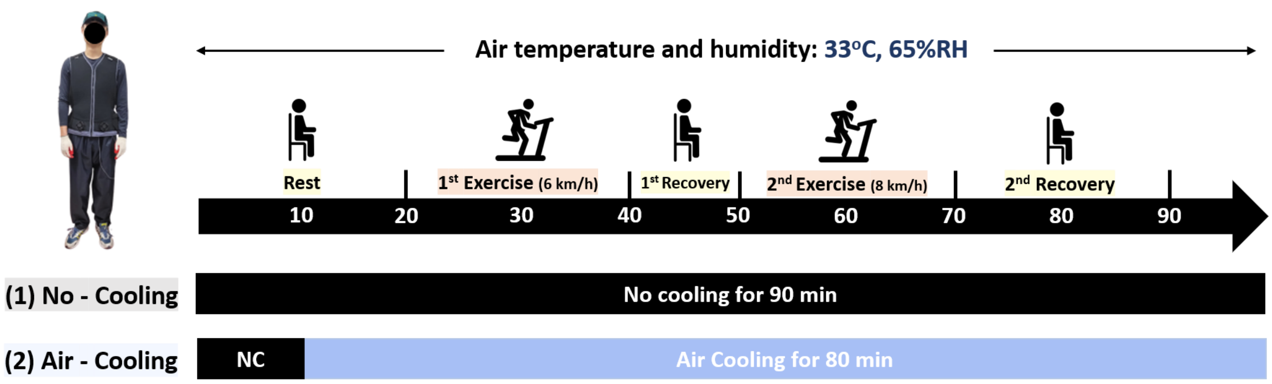

Figure 1. Experimental conditions and procedure.

Results and discussion
Rectal temperature was significantly lower for the Air-cooling condition than No-cooling condition during the exercise and recovery ($P < 0.05$). However, rectal temperature increased over 1.5^{o}C on average without any effective drop during the recovery for both experimental conditions. Mean skin temperature was significantly lower for the Air-cooling condition throughout the 70-min trial except the 1st Rest (Table 1). Among the ten skin

temperatures, significant differences were found on the chest, upper back, abdomen, and lower back temperature during exercise or recovery (*P* < 0.05). Total sweat rate was also smaller for the Air-cooling condition (850 ± 238 g/trial) than for the No-cooling condition (1,133 ± 455 g/trial) (*P* < 0.05). In terms of thermal sensation, subjects felt less hot for the Air-cooling condition than the No-cooling condition, especially during rest and recovery periods (all *Ps* < 0.05), but they still expressed score 3 ~ 4 (hot ~ very hot) during the 2nd exercise even wearing the air-cooling vest (Table 1). Subjects evaluated themselves as being less thermally uncomfortable when they wore the air-cooled vest, especially during the 2nd exercise and recovery, but the score for the air-cooling condition during the 2nd exercise was -2 ~ -3 (uncomfortable ~ very uncomfortable) (Table 1).

Table 1. Physiological and perceptual responses for the No-Cooling and Air-Cooling condition.

Phase (Last 3 min)	Rectal temperature (°C)			Mean skin temperature (°C)		
	No-Cooling	Air-cooling	*P*-value	No-Cooling	Air-cooling	*P*-value
Rest (17~20th min)	36.9 ± 0.2	36.9 ± 0.2	0.187	34.8 ± 0.4	34.4 ± 0.4	0.063
1st Exercise (37~40th min)	37.3 ± 0.3	37.2 ± 0.3	0.022	35.8 ± 0.4	35.3 ± 0.3	0.005
1st Recovery (47~50th min)	37.4 ± 0.3	37.3 ± 0.3	0.084	36.0 ± 0.4	35.2 ± 0.5	<0.001
2nd Exercise (67~70th min)	38.4 ± 0.5	38.2 ± 0.4	0.002	36.9 ± 0.3	36.3 ± 0.3	<0.001
2nd Recovery (87~90th min)	38.8 ± 0.5	38.6 ± 0.5	0.003	37.2 ± 0.5	36.2 ± 0.4	<0.001
Phase	**Overall thermal sensation**			**Overall thermal comfort**		
	No-Cooling	**Air-cooling**	***P*-value**	**No-Cooling**	**Air-cooling**	***P*-value**
Rest (19th min)	1.6 ± 1.0	0.9 ± 1.0	0.041	-0.7 ± 1.0	-0.5 ± 0.6	0.571
1st Exercise (39th min)	2.8 ± 0.4	2.3 ± 1.0	0.146	-1.9 ± 0.4	-1.6 ± 0.6	0.132
1st Recovery (49th min)	2.5 ± 0.8	1.2 ± 1.3	0.024	-1.3 ± 1.0	-0.9 ± 0.7	0.230
2nd Exercise (69th min)	3.8 ± 0.4	3.4 ± 0.8	0.071	-2.8 ± 0.3	-2.3 ± 0.7	0.039
2nd Recovery (89th min)	2.9 ± 0.7	1.5 ± 1.5	0.024	-1.9 ± 0.3	-1.1 ± 0.7	0.024

Conclusions

These results indicated that the air-cooling vest can alleviate physiological and perceptual heat strain even in a hot and humid environment. However, rectal temperature was maintained over 38.2°C and mean skin temperature reached 36.2°C along with hot and uncomfortable feelings at the end of the exercise even while wearing the air-cooling vest. Subjects felt neither cool nor thermally comfortable under the air-cooling condition. To conclude, wearing air-cooling vests could be effective for alleviating the heat strain of workers in hot and humid environments, but cooling solely from sweating-based evaporative heat loss might not be sufficient to maintain body temperature at a safe level and keep workers comfortable during heavy agricultural work. Air-cooling vests might be more effective for lower intensity work in hot environments with lower air humidity and higher sensible air flow, rather than for the present experimental conditions.

Acknowledgements

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Physiological impacts and subjective comfort feelings by the amount of the total heat transfer through materials

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Keywords
protective clothing, total heat transfer, physiological impact, subjective feeling

Introduction

The effect of the amount of the total heat transfer through materials on the physiological impacts and subjective comfort feelings were studied.

The amount of heat emission through protective clothing from our body is very important for comfort in hot environment or during vigorous activities. The total heat transfer from the body occurs during both the dry heat transmission such as radiation, convection, conduction and the evaporative heat transmission by sweating at the same time. The amount of total heat transfer depends on both gradients of temperature and humidity.

In this study, we collected eight samples and measured the amount of the total heat transfer for each sample. The physiological impacts on subjective panel wearing each sample were also determined such as MET (Metabolic Equivalent Task), rectal temperature, sweating rate, skin temperature, garment temperature etc. The subjective survey for the comfort feeling wearing the samples was done.

Materials and Methods

Eight clothing samples for summer use were selected from the market for the comparison between THL and the other subjective parameters. The specification of the samples was showed in Table 1.

Table 1. Sample specifications.

No.	Weight (g/㎡)	Thickness (mm)	Yarn linear density (Nm)	Fabric density (wales/cm *courses/cm)	Fiber composition
#A	300.0	1.05	1/48.9	14*18	Polyester 64%, Rayon 33%, Poly urethane fiber 1%
#B	151.2	0.49		25*19	Polyester 78%, Poly urethane fiber 22%
#C	156.2	0.53		36*26	Polyester 78%, Poly urethane fiber 22%
#D	138.6	0.47	116.9	33*20	Polyester 90.6%, Poly urethane fiber 9.4%
#E	131.7	0.40	116.7	21*32 `	Poly amide 91%, Poly urethane fiber9%
#F	112.4	0.29		33*49	Poly amide 87%, Poly urethane fiber 13%
#G	181.5	0.48		32*16	Polyester 90%, Rayon 10%
#H	165.4	0.58	50.3	15*21	Cotton 100%

Total Heat transfer were determined based on the ISO 20852. For the reference of the objective testing, MMT(Moisture Management test) were measured according to AATCC 195 and the change of the surface temperature of the sample after adoption of 1.3 mL distilled water (28±1)℃ at the environment (28±1)℃, (50±4)% R.H.

The physiological impacts on five subjective panels wearing four each selected sample with shorts, socks and running shoes were determined such as MET (Metabolic Equivalent Task), rectal temperature, sweating rate, skin temperature, garment temperature etc. Test environment is (28±1)℃, (50±4)% R.H. and the detail of the test program is shown in Table 2.

Table 2. Sequence detail of the program.

Sequence	Duration	Program
Rest 1	(0~10) min	Stabilization - standing
Exercise	(10~40) min	Walking in tredmil (2.1 mph)
Rest 2	(41~60) min	Recovery - standing

The subjective assessment was surveyed for the comfort feeling such as comfort level, humidity level and total comfort level using likert scale.

Results and discussion

As results, we found that the total heat transfer through materials has the relationship with the most of the physiological impact parameter such as MET, rectal temperature etc and with some of the subjective comfort feelings.

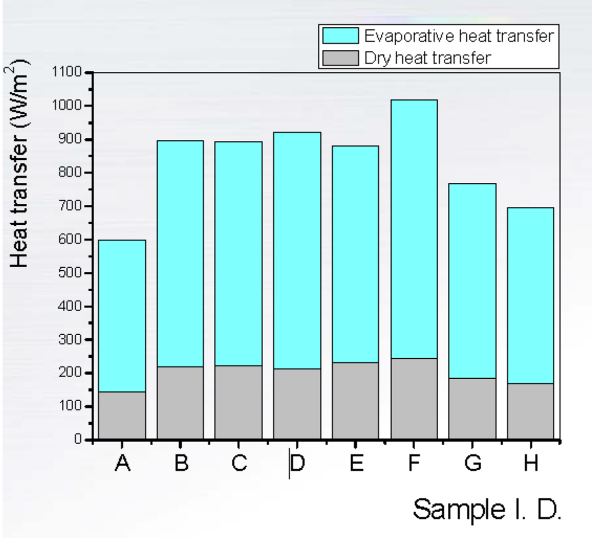

Figure 1. The amount of the total heat transfer.

Conclusions

Determination of the amount of the total heat transfer could be an option for the comfort evaluation of the protective clothing. Further study is also needed for the various protective clothing materials.

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Digital Human Models and Virtual Ergonomics of PPE Systems

Digital human models and virtual ergonomics of PPE systems – a standardization perspective

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Keywords
personal protective equipment, PPE ensembles, ergonomics, model, simulation

Introduction
Procedures for testing ergonomics issues concerning the use of personal protective equipment (PPE) have been developed for special groups, e.g. for firefighters involving human participants (1), and are gaining attention, with a focus on PPE systems, defined as any set of clothing or devices designed to be worn or held by an individual for protection against one or more health and safety hazards. This is corroborated by European initiatives for standardisation in this field (2) and a corresponding draft standard concerning testing the ergonomics of PPE ensembles using human participants (3).

Nevertheless, there is a need for "*testing methods which are simple, objective and cost-effective. Virtual testing and simulation offer a potential yet under exploited in this area*" (2). Adopting concepts for protective clothing design (4-6), Figure 1 presents six levels for evaluating the ergonomics of PPE systems, with control of the testing procedure decreasing from level 1 to level 6, whilst external validity, but also time requirements and costs will increase. Whereas levels 4 to 6 involve human test persons, level 3 analyses supplemented by methods from level 2 and 1 are shaping the area of virtual ergonomics of PPE systems.

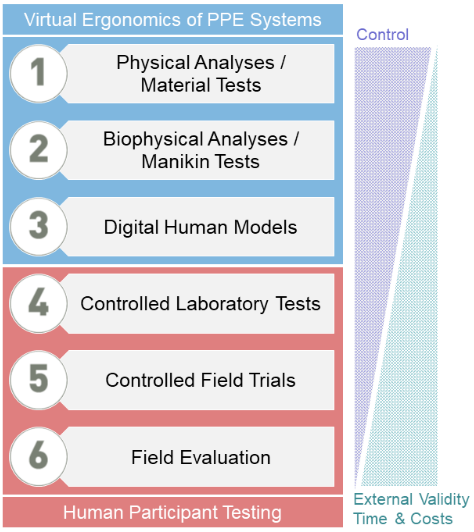

Figure 1. Levels for testing the ergonomics of PPE systems, adopted from protective clothing design (4-6).

Digital Human Models and Biophysical Tools
Simulation tools employing biophysical testing in connection with digital human modelling may help to develop design solutions to ergonomics issues at reduced costs compared to human participant testing, with numerous examples demonstrating their applicability to the thermal aspects of PPE use (7-10).

Though modern digital human models considering industrial work (11) also cover functional tests of vision, mobility/reachability or biomechanical load with relevance for human testing (3), their application to PPE use is rare.

Session on Virtual Ergonomics of PPE Systems at ECPC203
Recognizing the increased awareness for simulation tools supporting PPE ergonomics, a dedicated session on virtual ergonomics of PPE systems will be organized at the 10th European Conference on Protective Clothing (ECPC2023). The topic broadly covers the application of digital human modelling and/or simulation techniques to any (thermal, anthropometrical, biomechanical, sensory, comfort…) aspect related to testing the ergonomics of PPE items or systems. Contributions will include reports on dedicated studies and experiments as well as reviews and overview papers.

Standardization Perspective

The role for standardization in strengthening the development and usage of virtual ergonomics tools for PPE application will be of special interest. Therefore, a panel discussion will focus on the utilization of available standards, including methods from levels 4 to 6 (Figure 1) involving human participants (3), for supporting biophysical testing and simulation. In addition, we will discuss the desiderata to future standards for improving the application of digital human models, potentially coupled with biophysical testing and advanced measurement procedures, to PPE use conditions.

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Scenario dependent optimizing the protective ability of ppe against its physiological burden

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Keywords
modelling, ballistic protection, CBRN protection, physiological burden, PPE, optimizing

Introduction

The demands on protective clothing are strict and mostly contradictory, since they require the combination of optimal protection and optimal comfort (low thermal strain). Complicating factor to this issue is that a higher protection usually introduces higher physiological burden as well. This makes the design and development of effective protective clothing a complex task. Therefore an optimum between comfort and protection must be found. Optimization between physiological burden and protection is needed to create the ideal suit for a specific mission. The system requirements following from this optimization will lead to mission specific requirements for subsystems and materials of the clothing.

Until recently, garment design and testing was largely based on empirical research. A way to better understand this optimization question is by modelling all relevant processes and optimizing them by a parameter study of both comfort and protection parameters.

A software tool, which can be used to calculate both the comfort experience of protective clothing and its protective properties can be helpful in this regard. Therefore a special software tool was created “Brapa Clothing optimizer”. To achieve that, four different models were developed and implemented in the tool:

1. **A thermal strain model**, describing the thermo physiological effects resulting from wearing clothing
2. **A CBRN protection model**, describing CBRN protective clothing
3. **A ballistic protection model**, describing ballistic protective clothing with soft plates
4. **A ballistic protection model**, describing ballistic protective clothing with hard plates

Methods

Thermal physiology modelling

An important aspect in thermo physiology is the description of transport processes through and underneath clothing. Different approaches can be used to model these processes:

> **CFD approach**: The airflow around cylinders, covered with textile, was described by using CFD. See for instance (1-3).

> **Fundamental approach**: Continuity equations (mass balance for a slice of air underneath the clothing) describe the water vapor concentration underneath the around a body part. See for instance (3-5).

> **Resistance approach**: All processes are described in terms of resistances. See for instance (6), (7).

CBRN protection

There are different types of CBRN protective PPE, such as textile with carbon beads or carbon cloth or newer types of materials, like PPE with quantum dots (QD). Several different material types were modelled for the clothing optimizer. See for example (8).

Ballistic protection: Soft plates

Soft plate panels are described here as a set of layers of textile. When a projectile hits the soft plate, the kinetic energy of the projectile will be transposed into other types of energy (9), (10). For instance energy absorbed by tension and compression in the yarns, by shear plugging and by conical deformation.

By creating an energy balance in time, it is possible to calculate the kinetic energy in time, which in turn will be used to calculate the projectile velocity. By calculating different scenario’s (for instance different initial projectile velocities, it is possible to determine the Ballistic Limit Velocity, which is the minimal velocity the projectile must have to penetrate the soft plate.

Ballistic protection: Hard plates

Hard plates are described in a similar way as soft plates, where the kinetic energy of the projectile is transformed in other types of energy. A hard plate is regarded as set of different layers such as a front composite cover layer, a ceramic layer, a composite backing layer and a rubber layer.

Apart from energies, absorbed by the clothing, energies for deformation and erosion of the bullet play a role in hardplates (11).

Optimization

To optimise the comfort against the protection, it is very useful to plot a comfort parameter against a protection parameter. Various parameters affect the comfort experience and the protective performance. A parameter study of these parameters onto the protective performance and the comfort experience can lead to an optimal (scenario dependent) parameter set. Comfort parameters can for instance be the core temperature, the air velocity and the humidity underneath the clothing or the heart rate. An important protection parameter is the protection factor for CBRN clothing or for ballistic PPE, the ballistic limit velocity or the trauma (amount of deformation).

Results

An example of the Brapa Clothing Optimizer hardplate calculations is given in Figure 1 (left) and an example of optimizing the protective performance of CBRN clothing with QD against its thermal comfort is given in Figure 1 (right). Different lines represent QD's with different reactivity. The optimum suit would offer both a high protection and high comfort, which is at the top right of the figure.

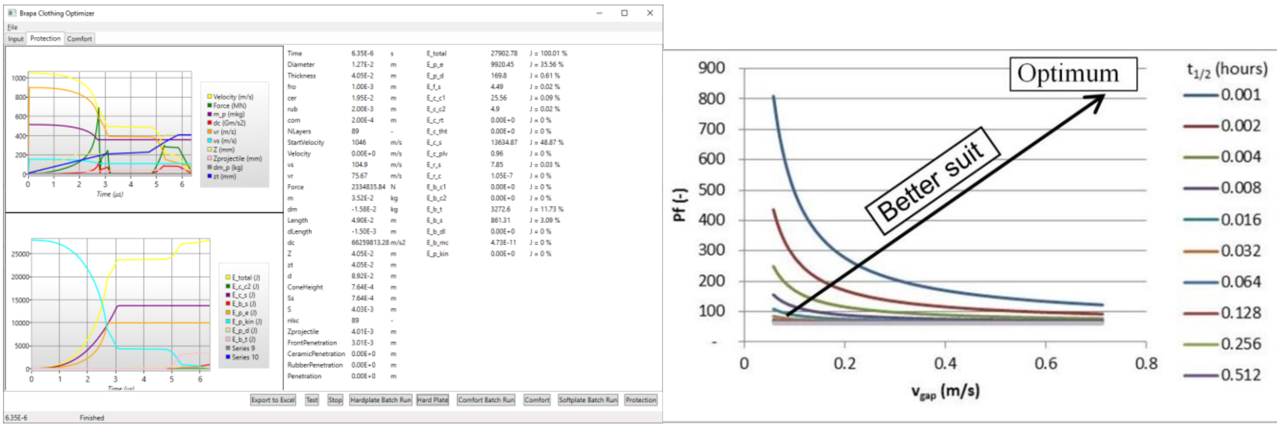

Figure 1. Example of a hard plate calculation (left), The protection as a function of the comfort (right).

Conclusions

A special software tool was developed "Brapa Clothing Optimizer", which can be used to evaluate the protective performance of PPE and its thermo physiological burden (thermal strain). Both CBRN protective clothing and ballistic protective clothing can be analysed, while including multiple clothing layers, such as undergarment, battle dress and protective clothing. Examples of parameters which can be calculated are:

> **Thermal strain** model: the core temperature and the heart rate of a person.
> **The CBRN protection**: the breakthrough and the protection factor.
> **The ballistic protection**: the ballistic limit velocity and the trauma.

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Development of a new testing protocol to evaluate cooling systems

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Keywords
personal cooling systems, thermal manikin, thermal comfort, thermoregulation, simulation

Introduction
Currently, the effects of climate change are more than evident. For example, the year 2022 in Spain has been the hottest year on record, and one of the driest in history according to the Spanish State Meteorological Agency AEMET (1). Our body needs to adapt to these new extreme cold and heat situations that we have begun to experience and that are expected to get worse in the coming years due to climate change. Thermal comfort is defined as the user's sensation of thermal well-being and this sensation has an influence on the wearer's physical and mental performance. In situations of cold or heat, thermal comfort is affected, and, for this reason, different mechanisms are required that allow the user to return to their state of well-being. These mechanisms may be the thermoregulatory system itself or an external mechanism that helps the body establish its equilibrium, like personal cooling or heating systems.

The performance of cooling garments can be evaluated by the ASTM F2371 (2) and the ASTM F2300 (3) standard. The ASTM F2371 standard quantify the cooling rate and cooling duration provided by a personal cooling system with a thermal manikin, without considering the variables associated with human physiology, and the ASTM F2300 evaluates the sensation and thermal comfort of these garments with the use of human subjects. This procedure describes a new testing protocol to evaluate, with a thermal manikin, the thermal comfort and sensation of the user wearing a personal cooling system.

Experimental
This study discusses the comparison between two methods of analysis using a thermal manikin.

Materials
The cooling vest used in this study is an air-cooling vest that blows air into the garment to allow the sweat evaporation. The vest has two small fans in waist part, right and left side, and two fans in back part, right and left side. Fans are connected to an external battery with an autonomy of 5 hours, according to the specifications of the product.

Instrumentation
The equipment used in both tests is a sweating manikin of 34 zones. The manikin is wearing a water saturated skin body suit and it is placed in a climatic chamber.

Test procedure according to ASTM F2371
The cooling vest is tested following the standard. In the first part of the test the manikin is wearing the vest without connecting the fans (PCS Baseline test) and when the manikin reaches the steady state (that is, the mean surface area and the power input according with the variation of the standard) we connect the fans and leave the test running for 2 hours more (PCS Performance test).

Test procedure according to the new testing method
The cooling vest is tested according to the new stablished testing method that combines a thermal manikin Newton of 34 areas with the Manikin PC Human Comfort Software. This software simulates the human thermoregulatory system in the body of the manikin to evaluate the thermal sensation and comfort while doing different activities. Activities are simulated according to the metabolic heat produced (Mets) and we must input this value in the software. Activities simulated in this study are activities with light effort (1.4 Mets), activities with light-moderate effort (2.3 Mets), activities with moderate effort (4.0 Mets), activities with heavy effort (5.0 Mets) and activities with very heavy effort (6.9 Mets). Each activity is simulated for 20 minutes. Environmental testing conditions for this test are according to the standard ASTM F2371. An additional test with the manikin without the vest is done according to the new testing protocol to compare the body behavior of the manikin nude and the manikin wearing the air-cooling vest.

For this evaluation, the parameters that we have considered to test are: T_{skin}, $T_{hypothalamus}$, thermal sensation and comfort.

Results

Results according to ASTM F2371 standard

The power input for the PCS Baseline test for the torso zone is 96 W/m^2 and the mean power input after connecting the fans is 348.3 W/m^2. The heat flux has increased at the same time that we have connected the fans.

Results according to the new stablished testing method

Figure 1 and figure 2 represent the skin temperature and the hypothalamus temperature of the manikin at each activity level. Figure 3 and figure 4 represent the thermal comfort and sensation of the manikin at each activity level.

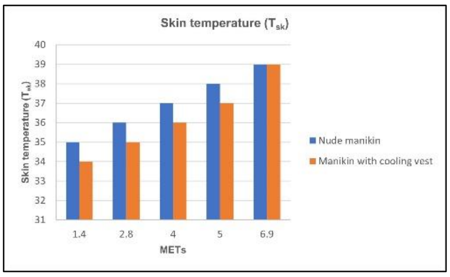

Figure 1. Skin temperature at each activity.

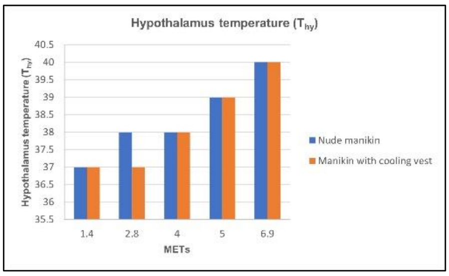

Figure 2. Hypothalamus temperature at each activity.

Thermal comfort index

METs	Index	
	Nude manikin	Manikin with cooling vest
1.4	-1 Slightly uncomfortable	2 Comfortable
2.8	-1 Slightly uncomfortable	2 Comfortable
4	-1 Slightly uncomfortable	0 Neutral
5	-1 Slightly uncomfortable	-1 Slightly uncomfortable
6.9	-1 Slightly uncomfortable	-1 Slightly uncomfortable

Figure 3. Thermal comfort at each activity.

Thermal sensation index

METs	Index	
	Nude manikin	Manikin with cooling vest
1.4	2 Hot	0 Neutral
2.8	2 Hot	0 Neutral
4	2 Hot	1 Slightly Hot
5	2 Hot	2 Hot
6.9	2 Hot	2 Hot

Figure 4. Thermal sensation at each activity.

Discussion

According to the new testing method, it has been found that for a light, light-moderate and moderate activity, the air-cooling vest has decreased in 1ºC the skin temperature of the manikin in comparison with the nude manikin. Also, the hypothalamus temperature of the manikin with the vest is lower at light and light-moderate activities, so for these reasons, the thermal sensation of the manikin is neutral at these activities and the manikin is in a comfortable state. This behaviour has relation with the results of the test according to ASTM F2371 where it has been found that the air-cooling vest has a high cooling rate with a minimum cooling duration of 2 hours. This cooling rate has been calculated with the manikin in a static position and this position corresponds to a light activity, so the high cooling rate of this vest corresponds to a hypothalamus temperature of the manikin of 37ºC with a neutral thermal sensation and a comfortable state.

At activities with heavy and very heavy effort, the sensation and comfort of the manikin is the same with and without the air-cooling vest, so in this case, the manikin doesn't feel a cooling sensation wearing this type of clothing.

Conclusions

This new stablished testing method with a thermal manikin can be complementary to the ASTM F2371 standard, and it is a practical, cheap, and objective test that can give information about different parameters associated with human physiology and two subjective parameters like thermal comfort and sensation.

The use of the air-cooling vest is beneficial for the user in activities that need low and medium efforts but in case of activities with high and very high efforts the use in this case is questionable.

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Firefighter clothing database: preliminary modelling and exposure predictions

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Keywords
station wear, turnout gear, exposure scenarios, insulation, evaporative resistance, IREQ, PHS

Introduction

Recently was created a Dutch firefighter clothing database, that covers both station wear and turnout gear individual items and clothing ensembles insulation, and selected clothing ensembles evaporative resistance (1). Preliminary simulations were carried out for (a) evaluating data use in the exposure prediction models, (b) planning the model validation by human experiments, and (c) getting a feeling of the standard models' limits and needs (2-4). As it was assumed that the use of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD; 3) for office work and activities at the station would be sufficiently accurate, then the focus was on Insulation REQuired (IREQ for cold; 2) and Predicted Heat Strain (PHS for heat; 4).

Methods

Seven tested clothing ensembles (1) covering the insulation range from 0.67 to 2.69 clo were selected for simulations: C1 (i_m=0.61, I_{cl}=0.67 clo, *AP*= 50 m³/m²s), C2A (i_m=0.49, I_{cl}=1.03 clo, *AP*= 20 m³/m²s), C3B (i_m=0.43, I_{cl}=1.25 clo, *AP*= 20 m³/m²s), C2G (i_m=0.42, I_{cl}=1.51 clo, *AP*= 20 m³/m²s), C9A (i_m=0.40, I_{cl}=2.09 clo, *AP*= 5 m³/m²s), C8 (i_m=0.36, I_{cl}=2.33 clo, *AP*= 5 m³/m²s), C4 (i_m=0.35, I_{cl}=2.69 clo, *AP*= 5 m³/m²s), where i_m is moisture permeability index, I_{cl} is clothing basic insulation, and *AP* is (estimated) air permeability of the outermost layer of the clothing system Although, the simulations were carried out with the work loads of 100, 165, 230, 290, 400 W/m², then this abstract presents only data on heavy activity (230 W/m²).

The specific simulated cold conditions combinations (IREQ) covered: air temperatures of -30 °C, -20 °C, -10 °C, 0 °C and +10 °C with mean radiant temperature equal to air temperature, relative humidity was always set to 85 %, and relative air velocity to 0.4 m/s. The specific simulated warm/hot conditions combinations (PHS) covered air temperatures of 15, 20, 25, 27, 29, 31, 33, 35 and 37 °C, mean radiant temperature was fixed to 70 °C, and air water vapour pressure to 1.7 kPa corresponding to relative humidity of 100, 73, 54, 48, 42, 38, 34, 30 and 27 % at the selected air temperatures, respectively. For PHS we considered additionally that the 1.8 m tall and 80 kg heavy person was in the standing posture, 100 % acclimatized and that drink was freely available. Where possible standard model was used (4). However, as it does not cover highly protective clothing and very heavy work, then for these the model was modified.

Results and discussion

Figure 1a shows the example of duration limited exposures (DLE) for heavy activity level (230 W/m²) in cold to maintain neutrality (low strain, $IREQ_{neutr}$ – allows up to 144 kJ/m² negative heat storage). For clothing ensembles with insulation above 1.51 clo there was no exposure limit. However, there the sweating should be avoided, and preferably clothing adjusted. The latter may be impossible in many rescue scenarios in hazardous environments, and/or during varying work tasks under high stress. Thus, for firefighter use the standard IREQ model (2) needs modification. With $IREQ_{min}$ (a high strain condition, with additional body cooling) DLE increases considerably for the given clothing combinations (Figure 1b). Considering intermittent activity during firefighter work and minimal possibility for adjusting clothing insulation during the tasks, then a range between $IREQ_{neutr}$ and $IREQ_{min}$ would be a good option for estimating DLE. The annexes of ISO 11079 (2) allow estimation of wind effects and cooling of bare body parts. Extremity protection must be considered separately, e.g. see EN 511 (5) on cold protective gloves.

Heat exposure is more relevant for the firefighter tasks. Commonly, a complete turnout gear is used also for technical rescue and wildland firefighting, even during summer. Station wear is also often used uniformly in different weather conditions. Figure 2 shows DLE curves that are based on the core temperature rise criteria of up to 38.0 (Figure 2a) or 38.5 °C (Figure 2b). The curves for all clothing ensembles are drawn in Figure 2a (core temperature criterion of 38.0 °C), while higher core temperature criterion sets no limits for exposure in lighter clothing. DLE for clothing ensemble C3B' (slightly reduced insulation of 1.20 clo) corresponds to standard PHS (4) and for C3B'' (1.25 clo) to modified PHS. For any longer exposures than 3-4 hours the body water loss may become a limiting criterion, instead. Lower exposure times for the lightest clothing ensembles (C1, C2A) compared to the next ensembles (C3B, C2G) may be related to lower protection against radiation heat. Also, the model performance in this range should be checked up. These simulations give some idea on the conditions for experimental planning. However, the predictions can't be considered reliable for the conditions outside the model validity range and experimental evaluation is recommended.

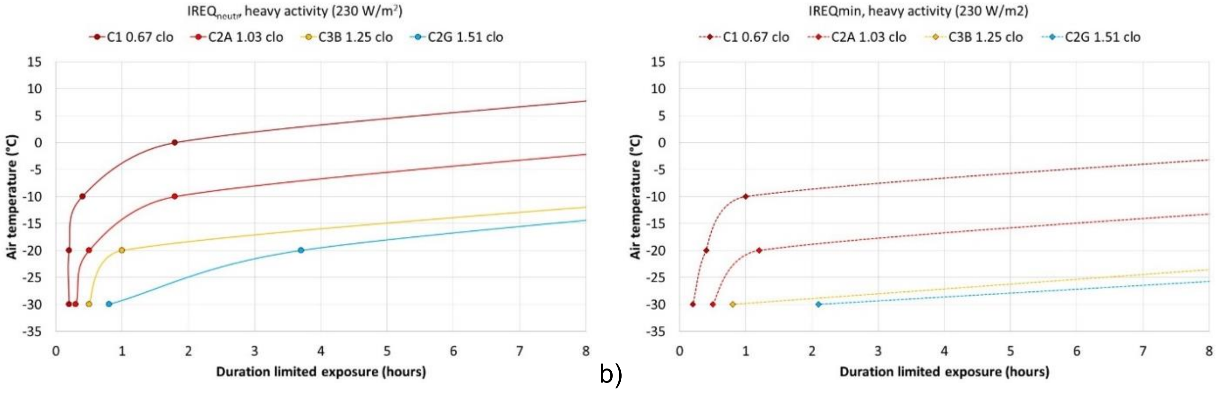

Figure 1. Duration limited exposure (DLE) for a) $IREQ_{neutr}$ (low strain) and b) $IREQ_{min}$ (high strain) in cold at heavy activity level.

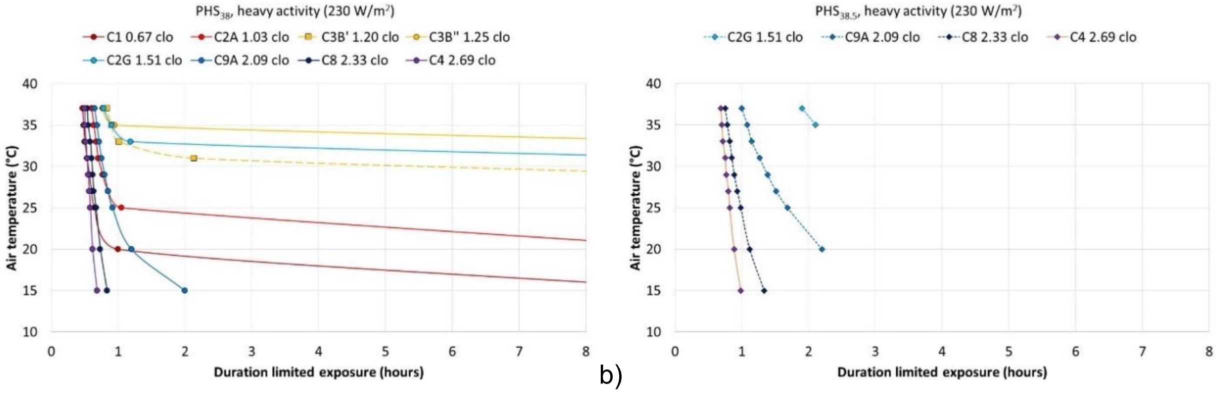

Figure 2. Duration limited exposure (DLE) by predicted heat strain (PHS) for heavy activity level if the exposure is limited by core temperature of a) 38.0 °C or b) 38.5 °C.

Conclusions

DLE analysis for Dutch firefighter clothing ensembles for cold and warm/hot environments was carried out. Some of the results can be considered reliable, e.g. station wear ensembles in cool, cold, warm and hot environments, where the clothing adjustment for comfort is possible However, the conditions where heavy sweating may occur (cool and cold) or which lay outside the validity range of PHS either by very heavy activity (incident scenarios!), permeability or insulation of a clothing ensemble, the predicted results may not be considered reliable. Thus, human experiments covering a wide range of the firefighters' exposure with well-defined clothing are recommended for validation, selection and development of the best fitting models. The described predictions, although not fully reliable, can serve as the basis for designing (pre)tests.

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Possibilities for analysis of the motion comfort of protective clothing using high speed (4D) body scanning

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Keywords
highspeed body scanning, motion comfort, automated analysis, protective clothing, firefighter clothing, 4D-Scanning

Introduction
The protective clothing is normally produced of special materials, where the protective function is the most important and the wear comfort remains secondary. In order to ensure sufficient protection the textiles are usually coated (for chemical protection), combined in larger set of layers (for instance bullet proof protection or for abrasion resistance), or have applied rigid elements (for stab protection). All these additional layers or elements increase significantly the rigidity of the material and reduce significantly the freedom of motion. This work presents a method for experimental analysis of the motion comfort of the user of protective clothing using 4D (high speed) body scanning.

Background
The human body and the clothing interact in multiple ways. The thermal exchange is important for the human body comfort (1) and depends on the materials and on the clothing construction. The gap between the body and the clothing is investigated by 3D body scanning for single postures (2), and changes significantly during the motion (3). Using 3D scanning the protection area of the clothing can be evaluated (4). All these methods and fundings would provide more useful information for the motion comfort if they become applied for a series of scans, so that the complete motion sequences can be analysed and the changes of the body form as well as required clothing dimensions can be obtained (4).

Methods
The 4D scanning system MOVE4D, developed by Instituto de Biomecánica de Valencia (IBV) and installed in the Scan Laboratory of TU Dresden has the possibility of creating up to 178 3D scans per second with spacer resolution of 1-2 mm. For normal motion the scanning frequency of 30-45 scans provides enough details for analysis of the motion of the body and its interaction with the clothing. For clothing for combat sports (Karate etc), already 60-90 frames per second are required. After scanning a series of files with point clouds are obtained and these can be analysed using different methods. In the current study the point cloud distances are used to analyse the relative motion of the clothing. The distance to nearest neighbour was used in 1954 for relations in populations (6) and as methods for comparison of point clouds were developed in the last 20 years more intensively (7). One of the common used distance is the Gromov-Hausdorff distance (8), implemented in several cloud analysis packages as Meshlab filter, CloudCompare or in Matlab.

Results and discussion
Each movement is composed of individual images and consists of individual point clouds. The individual point clouds can be displayed in different colours and provide detailed information about the position of the protective clothing on the body in different poses. The observation of the frame images of a motion on point cloud level is not easy, because behind the points of the front size also those of the opposite sides are visible (the time difference between two frames is 100 milliseconds). For better observation, the size of the points in the 3D visualisation must be adjusted to create a cloud without gaps between the points. Checking the Gromov- Hausdorff distances between the different images helps to visualise the movement of the cloud of points, but in the present case does not really provide useful information about the behaviour of the clothing or the places where the protective clothing affects the body in an uncomfortable way. The user obtains this information by visually viewing the scanned data. The distances between the individual images can be used to visualise the areas that do not move (blue colour, Figure 1 a and b) and the areas where a larger displacement is detected (green - red, Figure 1). Normally, the protective clothing is assumed to move and deform in the same way as the body, but a scan without clothing and a scan with clothing are required to detect this relative movement. Unfortunately, it is not possible for a human to perform a movement twice in an absolutely identical manner. Using the 4D scan to create an accurately realistic movement avatar of the usual movements of humans without protective clothing and then using these avatars with clothing simulation software would probably be the best method for analysing the relative movement between humans and protective clothing.

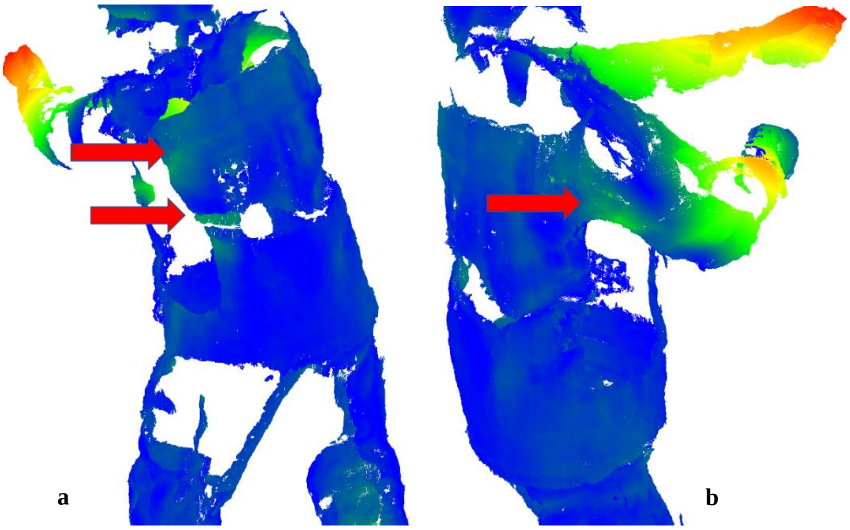

Figure 1: Point cloud (4D scan) of a person wearing firefighter protective clothing - computed Gromov-Hausdorff distance between two clouds (100 milliseconds of motion) and marked yellow/red areas where larger motion (distances) is detected- a and b viewed from different perspectives.

Conclusions

The 4D scanning provided large set of data with detailed positions of the body and protection vest. Those data allow exact analysis of the mechanical interaction between the vest and the body. The current manual observations provide more information than the automatic computed distances between the meshes. More work on the development of algorithms for automatic analysis of the deformation of the clothing has to be performed in the future in order the complete information from the high speed body scanning to be objectively analysed and used for development of better protective clothing.

Acknowledgment

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Employing human thermal modelling to assess the effect of sweat accumulation on body temperatures

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Keywords
human thermal modelling, human physiology, moisture modelling, sweat accumulation, sweat mapping, sensitivity analysis, uncertainty quantification

Introduction
We use an advanced human thermal physiology and clothing model that considers heat and moisture transport (1) to assess the effect of sweat accumulation on body temperatures. We conduct a sensitivity analysis to evaluate the impact of sweat map resolution and model geometry resolution on the model's predictions of sweat accumulation and body temperature under various activity and environmental conditions. Additionally, we quantify the impact of uncertainty in measured sweat rate on the uncertainty in the model's predictions. The model's results are compared with physiologically-controlled thermal manikin and human subject test results to gain further insights into the measurements.

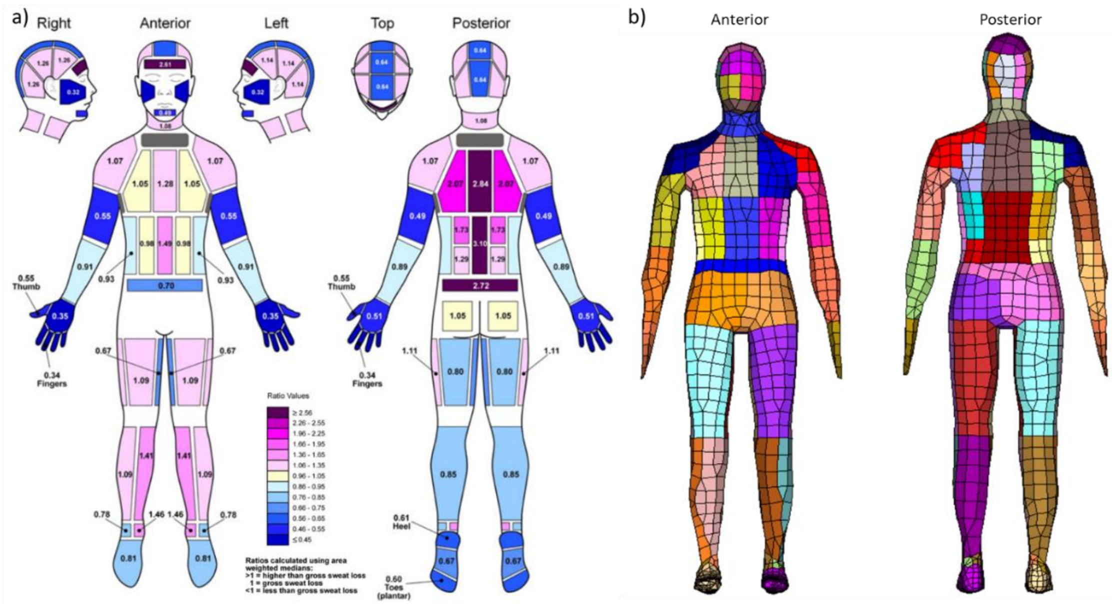

Figure 1. High resolution sweat map values from literature (5) (a) and incorporation of the sweat map into our high resolution human thermal model geometry (b).

Methods
Our human thermal physiology and clothing moisture models have been described in previous works (1-3). The human thermal model (HTM) solves the bio-heat transfer equation (4) on a nodal network describing a human. It considers physiological mechanisms such as metabolic heating, shivering, respiration, sweating, and peripheral vasomotion. The HTM allows specification of a custom sweat map describing the relative sweat rates in different body regions. In this work, we replaced the HTM's 20 and 35 zone sweat maps with a higher resolution sweat map (69 zones) from the literature (5) (Figure 1). We compared model results between the higher and lower resolution sweat maps and human geometries to assess the sensitivity of the results to the resolution.

Additionally, model predictions were compared to manikin and human subject test results. In both the manikin and human subject tests, an athletic clothing ensemble was used, consisting of a tight-fitting long-sleeve UnderArmour base layer shirt and shorts. The tests were performed in a climate-controlled chamber (25 °C, 50% relative humidity, 1 m/s wind) and consisted of an activity protocol of 15 min resting, 45 min of heavy exercise, followed by 15 min of resting. In the human subject tests, twelve male subjects, ages 18-30, of moderate physical fitness performed the activity protocol. Two activity levels were considered for the exercise portion (4 MET vs. 6.5 MET), and two ending ambient conditions were considered for the ending rest portion (25 °C vs. 15 °C, 50% relative humidity). Local skin temperatures at four locations (upper arm, upper leg, chest, and lower leg), core temperature, and whole body sweat loss were compared to the human model with two geometry resolutions and two sweat map resolutions. Whole body mean skin temperature was estimated as a weighted average of the four measured local skin temperatures (6).

Uncertainty quantification was performed by running the HTM model 100 times where the sweat map values for each run were sampled from Gaussian distributions for the normalized regional sweat rates, which were defined using the results reported in Ref. 5.

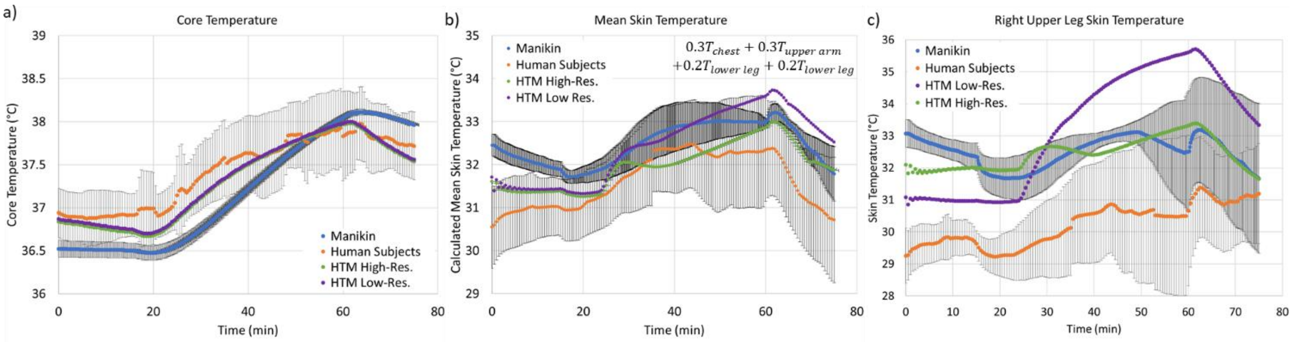

Figure 2. Comparison of core temperature (a), mean skin temperature (b), and upper leg skin temperature (c) results from the HTM, manikin tests, and human subject tests for the 6.5 MET activity level and 25 °C ending ambient temperature condition.

Results and Discussion

In general, the model was able to reproduce the trends in core and skin temperatures observed in the manikin and human tests (Figure 2). Using the low resolution human geometry yielded nearly identical results to the high resolution model, likely because the symmetrical boundary conditions in this indoor environment scenario cause the more detailed radiation calculations in the high resolution geometry to be unnecessary. The main impacts of sweat map resolution were on local liquid sweat accumulation and local skin temperatures. The high resolution sweat map's mean skin temperature prediction was closer to the test data in the second half of the simulation than the low resolution sweat map due to better agreement with two out of the four measured local skin temperatures (upper arm and upper leg).

Uncertainty in the normalized regional sweat rates resulted in large uncertainties in local skin temperature predictions of several degrees Celsius in some body segments. These uncertainties were mainly due to a large uncertainty in sweat accumulation and the times in the exposure when sweat starts accumulating, starts drying out, and completely dries in individual body segments. The uncertainty in core temperature predictions was negligible and the uncertainty in whole-body mean skin temperature was < 0.5 °C.

Conclusions

This work demonstrates how human thermal simulation can provide further insights into the impact of sweat accumulation, which may be difficult to derive from test measurements alone. We find that the HTM is insensitive to model geometry resolution in the indoor environment scenario studied. Using a higher sweat map resolution has the most significant impacts on local skin temperatures and sweat accumulation and improved the HTM's agreement to measured data. Uncertainty in regional sweat rates due to a combination of measurement error and variability between different humans can result in very large uncertainties in local skin temperature, local sweat accumulation, and therefore local comfort. This suggests that the values for any particular individual can deviate significantly from the median values that are predicted by a model. The use of higher resolution sweat maps to improve an HTM's predictions of the mean values for a population should be combined with uncertainty quantification to understand the variability in those values. In future work, the impact of uncertainty of other model parameters such as convection coefficients will be studied.

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Manikins and models

Applicability of human thermophysiological model for prediction of thermal strain in PPE

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Keywords
personal protective equipment, predictor of thermal stress, thermophysiological models, thermal manikin, climatic chamber

Introduction
Using of personal protective equipment (PPE) is an indispensable way how to protect the human body in hazardous environment with the risk of CBRN agents. On the other hand, the PPE poses a barrier to evaporative heat dissipation therefore increasing the body heat accumulation. Resulting thermal stress is one of the most important harmful factors, which causes impaired work performance and subsequent occupational accidents. To predict the risk of human exposure to the overheating, models and indexes intended for predicting human thermal stress, are widely used (1). In our study, we compared Predicted Heat Strain Index (PHS) (2) and Fiala-based Model of Thermal Comfort (FMTK) (3) with experimental data from thermal stress tests with human probands wearing PPE in a climatic chamber (4, 5). Based on the results, we developed a user-friendly computational tool Predictor of the Thermal Stress (PTS) for estimation of thermal stress in PPE considering the input data. The PTS tool is based on an extensive database of simulated calculations using FMTK model based on PPE characteristics, environmental conditions, individual parameters and expected workload, and verified according to the results from real tests in climatic chamber. The PTS showed to be a helpful tool for estimation of the allowable work time limit due to thermal stress in PPE under various conditions.

Methods
In our study, we covered four types of PPE (light chemical protective clothing Tychem F ® DuPont™, with protective mask, fully encapsulated suit OPCH90PO by Ecoprotect with self-contained breathing apparatus (SCBA), filtration NBC suit FOP96 by B.O.I.S. with protective mask, and firefighter suit Tiger Plus by DEVA with helmet without air-ways protection or with helmet and SCBA). At first, we measured PPE characteristics – thermal resistance and evaporative resistance of the four types of protective ensembles using 34-zone Newton thermal manikin. The same four types of protective ensembles were then examined for induced thermal stress in 150 real tests with a group of 10 volunteers in the climatic chamber under four various ambient conditions (-10 °C, 5 °C, 25 °C, 35 °C, air velocity 0,2 m/s, physical activity – walking on a treadmill 4 km/h, 10° slope). We monitored physiological parameters, namely heart rate (HR), body core (rectal) temperature (T_{re}), skin temperature (T_{sk}) and others. The test was terminated when either of time limit (120 min), heart rate limit (HR_{lim} = 220 – age) or body core temperature limit ($T_{re,lim}$ = 38.5 °C) was achieved or in case of proband's demand (headache, nausea or other discomfort). Mathematical simulations using two thermophysiological models PHS and FMTK were performed for the same conditions, measured PPE thermal-insulation characteristics and "universal proband" and the results were compared with data obtained from the real tests with human probands.

Results and discussion
Both models are well usable for air-permeable ensembles with moderate moisture index i_m (0.3 – 0.4 for water vapour-permeable NBC suit and fire-fighter suit). But, for impermeable protective ensembles with low i_m (under 0.1), the more complex FMTK model showed to produce more realistic values. However, the FMTK model based on the Matlab application is too technically and time-demanding to be simply used by the common PPE users. For this reason, we developed the user-friendly application Predictor of the Thermal Stress – PTS (Figure 1) for estimation of the allowable time limit in PPE. The PTS tool is based on searching in database covering extensive tables of more than 11 000 combinations of varied input data calculated using the FMTK model. In the PTS tool, it is currently possible to set input data by choosing among the five types of protective ensembles, individual parameters of the user, ambient conditions, work regime, expected metabolic rate and planned time of the activity in PPE. The immediate output data show estimated maximum allowable time limit (reaching of $T_{re,lim}$ = 38.5 °C) as well as T_{re} 38 ° C and 39 °C, ability to finish the planned work task, estimated heat balance and others. The applicability of the optimized PTS tool was verified in series of real laboratory tests with a group of volunteers, and more investigations are ongoing.

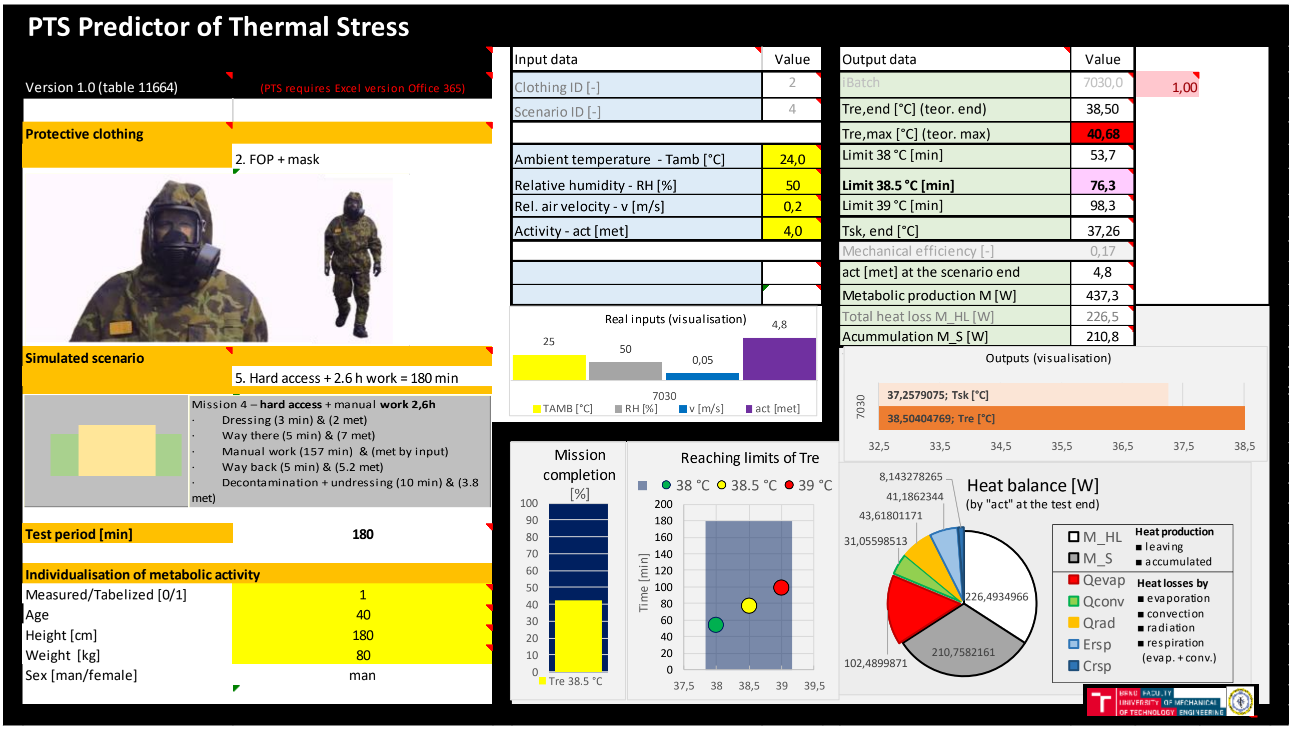

Figure 1. User interface of the Predictor of Thermal Stress tool.

Conclusions

Thermal comfort is important issue for safe working in PPE against CBRN agents. Heat stress is a problem particularly for impermeable suits but cannot be ignored neither for water vapour-permeable suits including firefighter suits. Essential preventive measures against the overheating cover reasonable estimation of actual conditions and task demands in PPE. For this, thermophysiological models can be used as a tool for estimation of maximum allowable time limit for activity in PPE. We have developed the user-friendly tool Predictor of the Thermal Stress which may help with the reasonable estimation. It is supposed to be used specifically for training purposes or exercise planning or for long-time demanding work tasks in PPE or for research purposes during the PPEs development.

Acknowledgements

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A comparison of thermal manikin test methods to assess cooling efficiency of cooling vests

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Keywords

cooling vest, cooling efficiency, heat illness, manikin test, thermal manikin, sweating thermal manikin

Introduction

There have been several attempts to develop test protocols for cooling vests using a thermal manikin (1, 2). Ciuha et al. (1) suggested the 8-h protocol using a thermal manikin without sweating activated, which may cause an underestimation of cooling performance especially for the air-cooling vest. On the other hand, ASTM F2371 (2) suggested a shorter measurement time using a sweating thermal manikin, but there are still concerns that it could overestimate the performance of cooling vests worn in the hot and humid environment because it requires testing under conditions of 35 °C and 40 %RH. In this context, the current study aimed to compare the performance of five types of commercial cooling vests based on three thermal manikin test protocols and to derive a test protocol suitable for the hot and humid environment.

Methods

A total of 5 types of cooling vests were evaluated (Table 1). Among them, the Inuteq Bodycool Hybrid was tested in three different modes (e.g. IH wet, IH PCM, IH hybrid). Three protocols (A, B, C) were performed for five cooling vests using a thermal manikin (Newton 34 Zones) (Table 2). The heat flux supplied to maintain the skin temperature of thermal manikin at 35 °C was recorded at 1 minute intervals. In each trial, the manikin wore an identical clothing ensemble including briefs, long-sleeved shirts, and trousers under cooling vests. With respect to results from the protocol A, average cooling rate (P_{avg}, W/m^2) and duration of cooling (T_c, min) were calculated in accordance with Ciuha et al. (1), where T_c was defined as the time at which heat flux ≥ 20 W/m^2. Resultant values from protocol B and C were also calculated as outlined in ASTM F2371 (2). The heat flux when the cooling vest was not operated was defined as P_{base} (W/m^2), the duration time when the difference between heat flux and P_{base} was greater than 50 W/m^2 was defined as T_c, and the average heat flux during T_c was defined as P_{avg}. The effective cooling rate (P_{eff}, W/m^2) was calculated as the difference between P_{avg} and P_{base}. IH wet was excluded from the current analysis as its P_{base} was too high to calculate a valid P_{eff}. P_{avg} from protocol A and P_{eff} from protocols B and C were considered as a key parameter representing cooling efficiency.

Table 1. Information of the cooling vests measured.

Code	Cooling concept	Product name (Country)	Size
TACV	Air-cooling (Built-in-fan)	Teijin Active Cooling Vest (JP)	S
COMP	Liquid-cooling	CompCooler UniVest (US)	XS/S
IH wet	Evaporation	Inuteq Bodycool Hybrid (NL)	S
IH PCM	PCM		
IH hybrid	Evaporation and PCM		

Table 2. Environmental conditions and procedures of thermal manikin test methods.

Protocol	Sweating system	Experimental condition	Reference
A. No_Sweat	Not used	35°C, 35%RH	Ciuha et al. (2020)
B. Sweat_Hot&dry	Used	35°C, 40%RH	ASTM F2371
C. Sweat_Hot&humid	Used	35°C, 70%RH	"Modified" ASTM F2371

Results and discussion

The air-cooling vest (TACV) showed the largest difference in cooling efficiency depending on test protocols. In the protocol A, at which the evaporation of manikin's skin was not activated, the cooling efficiency was almost zero, showing the P_{avg} of 0.8 W/m^2. In the protocols B and C, at which manikin sweats accelerating evaporative heat loss, the cooling efficiency prominently increased. The liquid-cooling vest (COMP) barely showed differences by protocols, and IH hybrid showed much better performance than IH PCM when the test protocol A was carried out, but the difference was disappeared in the results from protocol B and C.

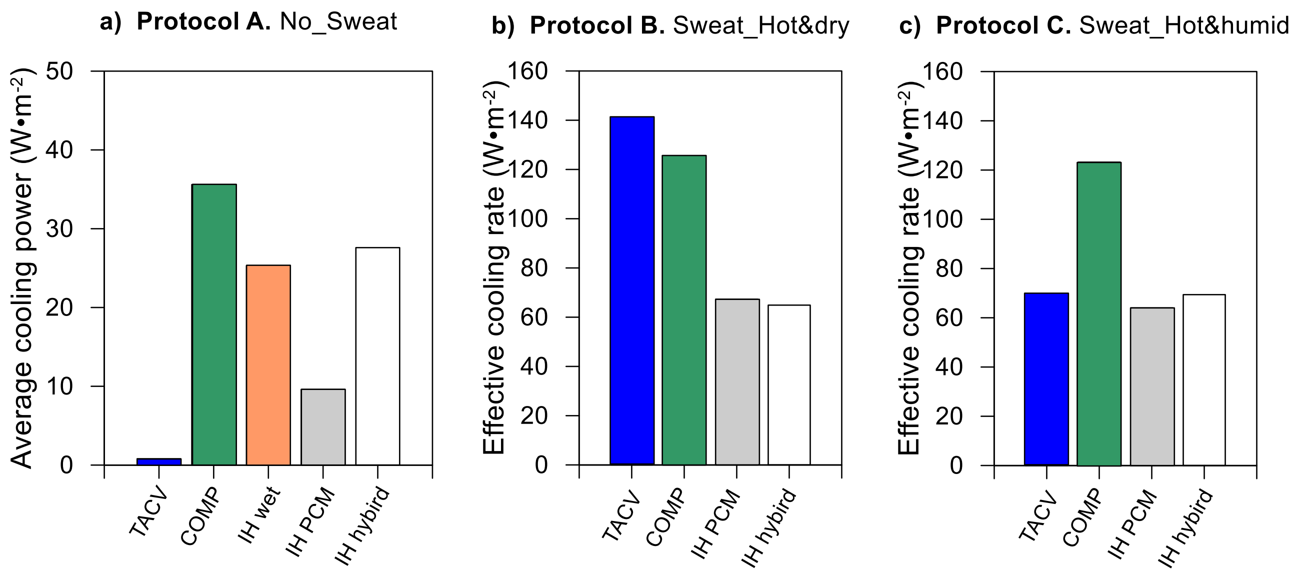

Figure 1. Average cooling rate and effective cooling rate of cooling vests.

Conclusions

The test protocol of Ciuha et al. (1) would be useful in that it can quantitatively compare convective and conductive heat loss, and can consider problems of short working time of batteries and a maintenance of coolant temperature. However, the current study demonstrated that this protocol substantially underestimate cooling performance of air-cooling vest, especially which consists of built-in fans. ASTM F2371 (2) can be used to evaluate the performance of air-cooling vests for use, but it is recommended to adjust environmental conditions for the purpose of an application to hot and humid condition.

Acknowledgements

This research was supported by a grant (2022-MOIS41-004) of Citizen-customized Life Safety Technology Development Program funded by Ministry of Interior and Safety (MOIS, Korea).

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Comparison of clothing measurements on 2 manikins in the light of size and fit

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Keywords
insulation, evaporative resistance, firefighter, station wear, turnout gear, thermal manikin tests

Introduction
Several earlier studies have compared data from different manikins wearing the clothing that was selected to fit each particular manikin (1-3). In case of new clothing prototypes different sizes are often not available. Therefore, in this study we were interested to see the differences in measurement output between two manikin types wearing the same clothing. For any similar future considerations and measurements, an aim of the analysis was to evaluate how much of the differences could be explained by evidence based sizing and environmental factors.

Methods
Thermal manikin Tore at Lund University, Sweden and Newton at Ministry of Defence, Netherlands were used for comparison. The correct size of clothing was selected for Tore, while Newton used the same clothing. Newton was slightly taller and slimmer with a total body surface area of 1.81 m^2, and Tore somewhat shorter, but thicker with a total body surface area of 1.77 m^2. The proper clothing size for Tore is Large (L) and for Newton is Medium (M). Thus, Newton in Tore's clothes wore a one size larger clothing ensemble than appropriate, which also caused a difference in clothing area factors (fcl) for all ensembles. Fcl was estimated by 2 photos based photographic method (2). The manikins and the tested clothing ensembles are shown in Figure 1. Detailed clothing descriptions are available in a related clothing database paper (4). The tests were carried out at different locations with different environmental conditions. On Tore, the air layer and clothing ensembles C2, C2A and C2G were tested at 20 °C, and C6 and C9A at 10 °C with air velocity of 0.18 m/s, while all tests on Newton were carried out at 21.7 °C with 0.04 m/s air velocity. As the air velocity stayed below 0.2 m/s and the temperature gradient between the clothing surface and environment in any of the conditions was low, no considerable differences due to natural convection were expected.

Figure 1. Clothing ensembles on both manikins with coding. Top row: Tore, bottom row: Newton. Itot – clothing total insulation, fcl – clothing area factor.

Results and discussion

Figure 2a shows the differences in clothing total (Itot) and basic (Icl) insulation and clothing area factor (fcl) between the two manikins, and 2b shows the evaporative resistances measured on Newton and Tore, and the differences between the ensembles. In literature it can be found that a one size larger clothing set may add about 4 % to the insulation (5). It is known that with increasing air gap the increase in insulation reduces (6) whereas evaporative resistance keeps increasing linearly with an increasing air gap (6) or number of added layers (7). In large, our results confirm these earlier findings. However, not all differences in insulation and evaporative resistance can be explained by garment size and fit, and therefore have to be attributed to other differences in manikin construction and regulation, e.g. manikin material, openings in the body, skin material, the skin's contact with the manikin surface and ways of dressing. Other limiting factors contributing to differences are related to test environments, e.g. different air speeds and flow directions at the test locations (in the present case minor influence, as described in methods), while these can be accounted for, and different people dressing the manikin, that is more difficult to quantify.

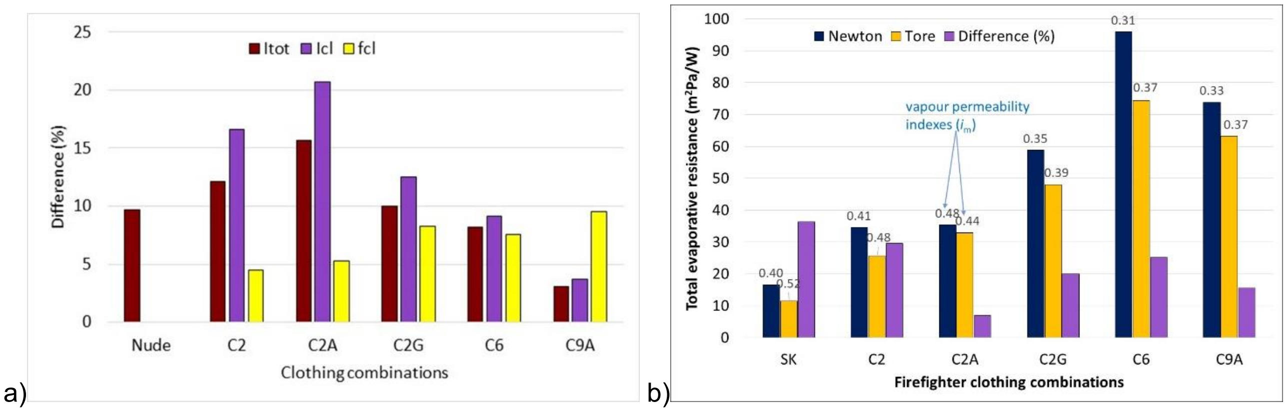

Figure 2. Differences in a) clothing total (Itot) and basic (Icl) insulation and clothing area factor (fcl), and b) in evaporative resistance of the ensembles between the manikins. SK – nude manikin with textile skin.

Conclusions

Certain differences in manikin test results can be explained by the size or air gap thickness of the clothing ensemble, while further analysis is required in order to figure out other influential factors and their magnitude.

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New materials and evaluation methods

Research and development of simplified ways to comprehensively evaluate thermophysiological comfort for complex PPE garment systems

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Keywords
thermal insulation, breathability, sweating, thermal manikin, wearer trial, PPE

Introduction

Clothing, especially personal protective equipment (PPE), has the primary task of protecting the wearer from external influences (1). As a homoiothermic being humans must keep their core body temperature constant by expending energy (2, 3). Clothing can support or interfere with human thermoregulation. Good thermophysiological comfort has been shown to have a positive influence on the wearer's physical and mental performance; under extreme stress situations, thermophysiological comfort (e.g., firefighter protective clothing, cold weather protective clothing) can even be lifesaving (4-6).

The performance requirements and requirements for the design and construction of PPE are specified in Regulation (EU) 2016/425 and the corresponding mandatory standards, such as DIN EN 469 for firefighters PPE or DIN EN ISO 11611 for welding PPE. To ensure the greatest possible protection for the wearer, the mentioned standards mainly include requirements relating to protection against, for example, liquid metal splashes, heat and flames, chemicals, and moisture, as well as visibility through reflective strips. However, characteristic values for comfort are also playing an increasingly important role in the EU today.

Thermophysiological parameters are characterized using the so-called sweating guarded hotplate. Here, both the thermal insulation (thermal resistance, Rct) and the breathability (water vapor resistance, Ret) of textiles can be determined. These characterizations are carried out on the two-dimensional textile as material-specific parameters, whereby single-layer as well as multilayer textiles can be characterized. Regarding thermophysiological wearing comfort, which has so far been of secondary importance in the normative requirements for protective clothing, only water vapor transmission resistance (breathability; Ret) is often required as a mandatory criterion. However, this only describes a state of low physical activity and cool, moderate climatic conditions, i.e., moderate vapor sweating. However, under real-life conditions of use, warm ambient conditions and heavy physical exertion, wearers of PPE sweat significantly more (liquid perspiration). This wearing situation can no longer be adequately described by the water vapor transmission resistance Ret alone (7).

The EU is therefore endeavoring to evaluate thermophysiological wearing comfort more comprehensively in standards for protective clothing to be able to better evaluate the actual wearing situation of PPE in terms of measurement technology. This requirement therefore means an increased effort in terms of measurements in product development, as additional key figures must be recorded. Existing methods for evaluating the thermophysiological properties of materials during liquid perspiration (buffer effect of liquid perspiration Kf - Hohenstein, sweating torso - EMPA) are carried out on the textile surface. Additional measurements on thermal manikins are necessary to evaluate the fabrication. Thus, for a comprehensive description of the thermophysiological parameters of PPE, several key figures are necessary, thus the measurements are currently very time-consuming and cost intensive.

Within the funded research project "Comfort assessment PPE" (IGF 21396N), an economical method for the determination of the holistic thermophysiological wearing comfort of PPE will therefore be developed. For this purpose, tests with thermal manikins will be carried out. This ensures that the fit of the clothing is considered in the measurements. Since work with higher, liquid sweat rates is to be simulated as realistically as possible, the tests are carried out with the sweating thermal manikin "Sherlock". By determining the wearing comfort by means of a sweating thermal manikin, several parameters as well as the fabrication can be considered at the same time and thus the costs as well as the time for the characterization can be reduced.

Methods

Eight PPE clothing systems from the area of heat protection and weather protection clothing, which are state of the art, were tested with the use of a sweating guarded hot plate (Skin Model, DIN EN ISO 11092 and with higher sweat rates DIN EN 17534) to determine the physiological wear comfort. Also, measurements with a thermal manikin (DIN EN 15831), a new established test protocol with the sweating, thermal manikin acc. ASTM F2370 and DIN EN 17528 as well as wearer trials with four male test persons have been done. For the wearer trials the test persons were equipped with temperature and moisture sensors in a climate chamber (23, 50% r.h.). All test persons evaluated the subjective comfort sensation during the test period. To determine the sweat absorbance, each piece of clothing was weighed at the beginning and the end of the wearer trial.

Results and discussion

Skin Model Measurements

The results of thermal insulation Rct and breathability Ret show values in a normal range for the respective PPE and meet existing normative requirements. Garments from the heat protection sector have higher values than weather protection PPE. To represent a stronger physical effort and thus a more realistic application metrologically, the buffer effect of water vapor Fd and buffer effect from the liquid phase Kf were determined. Overall, the measured clothing systems performed as expected. The layer structures for the firefighter jackets exhibit very good Kf values. Through the measurements on the skin model, it was possible to characterize the clothing systems on a material-specific basis.

Manikin Measurements

The thermal insulation Rc of the complete clothing systems was measured with the thermal manikin "Charlie" (Hohenstein) and the sweating thermal manikin "Sherlock" (Newton type, Thermetrics). When comparing the values, a correlation was found. In addition, a new test protocol was developed with the sweating thermal manikin to determine the breathability Re of complete clothing systems. Sweating rates from the literature provided the basis for this. The investigations of the PPE with this test protocol are currently still ongoing.

Wearer trial

During the wearer trials the temperature and relative humidity in the microclimate above the skin, the total sweat production of the test persons and the sweat uptake of the individual garment components during the test period have been measured. These data will be correlated with the results of the sweating thermal manikin "Sherlock". The subjective comfort sensation of all test persons correlates with the measurements of the temperature and relative humidity in the microclimate above the skin. It could be shown that the relative humidity has a significant influence on the wearer's comfort.

Conclusion

PPE clothing usually consists of several textile layers and clothing parts to meet the normative requirements for protecting the wearer. Based on these requirements, we investigated the heat and moisture management of PPE. from the field of heat protection and weather protection for this purpose material-specific thermal physiological parameters were determined with the skin model considering different sweating rates. In addition, the influence of the fabrication of complete clothing systems by means of manikins was investigated. Therefore, a novel test protocol with the sweating thermal manikin could be developed, so that the overall comfort of the PPE can be determined in a simple way. To validate the new test protocol, measurement-monitored wear tests were also carried out with test subjects in a climate chamber. The subjective perception of the test subjects allows conclusions to be drawn between the objective data and human perception. The final studies will be completed and evaluated in a timely manner so that the findings can be presented in full at the conference.

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A new approach to estimate R_{et} values

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Keywords
manikin, first responder, clothing, prediction model, evaporative resistance

Introduction

Clothing properties such as thermal insulation and evaporative resistance (R_{et}) are determined based on thermal manikin tests which require expertise, time, and infrastructure. As this provides an obstacle to most clothing manufacturers to properly evaluate the functionality of their clothing, alternative approaches to estimating the insulation and R_{et} could be beneficial. When evaluating ensemble clothing insulation, a method to sum all the individual garment insulation values is available in ISO 9920 (1). In this study, we propose a new approach to estimate R_{et} of clothing based on measurements on firefighter (FF) and ambulance (Amb) clothing.

Methods

In this study, data from previous studies was applied to obtain an equation to estimate R_{et} of clothing worn by first responders, the data is from a firefighter study (FF) (2) and an ambulance clothing study (Amb) (3). The data was collected using a thermal manikin in standing position according to ISO 15831 (4) and using ISO 9920 recommendations (low air velocity) (1). Initially the model was derived using the FF data and later the Amb data was included to further improve the model. The model was derived using multiple linear regression modelling in RStudio version 1.4.1717 (RStudio, U.S.A.). A root mean square deviation (RMSD) analysis was performed as suggested by Haslam and Parsons (1994) (5) where a RMSD lower than standard deviation (SD) of the measured value indicates a valid prediction.

Results and discussion

The multiple linear regression model that was derived using the data from the FF study and later both the FF and the Amb studies found that the following variables were statistically significant when estimating R_{et} of the ensemble: the dry weight in kg of the ensemble (A), the number of layers on; upper body (B), lower body (C) and head (D). The first model using only FF data had different values for A, B, C and D, and was applied to the Amb clothing with the average error of -8,1%.

The final equation resulting from the linear multiple regression model was:

$$R_{et}\_estimated = -26{,}91 - 2{,}73*10\text{^}{-3}*A + 10{,}00*B + 22{,}24*C + 18{,}96*D$$

The adjusted R-squared was 0,90 for the multiple linear regression model. The RMSD values and standard deviation for the R_{et} measured values can be seen in Table 1. The RMSD for both FF + Amb is much lower than the SD of the measured R_{et} values which indicates a valid prediction.

Table 1. The root mean square deviation values and the standard deviation calculated for all the sets in the studies.

Data	SD (m^2Pa/W)	RMSD (m^2Pa/W)	Error (%)
R_{et}	32,2		
FF + Amb		4,4*10^-5	2,60
FF		29,3	-4,33
Amb		204,2	58,51

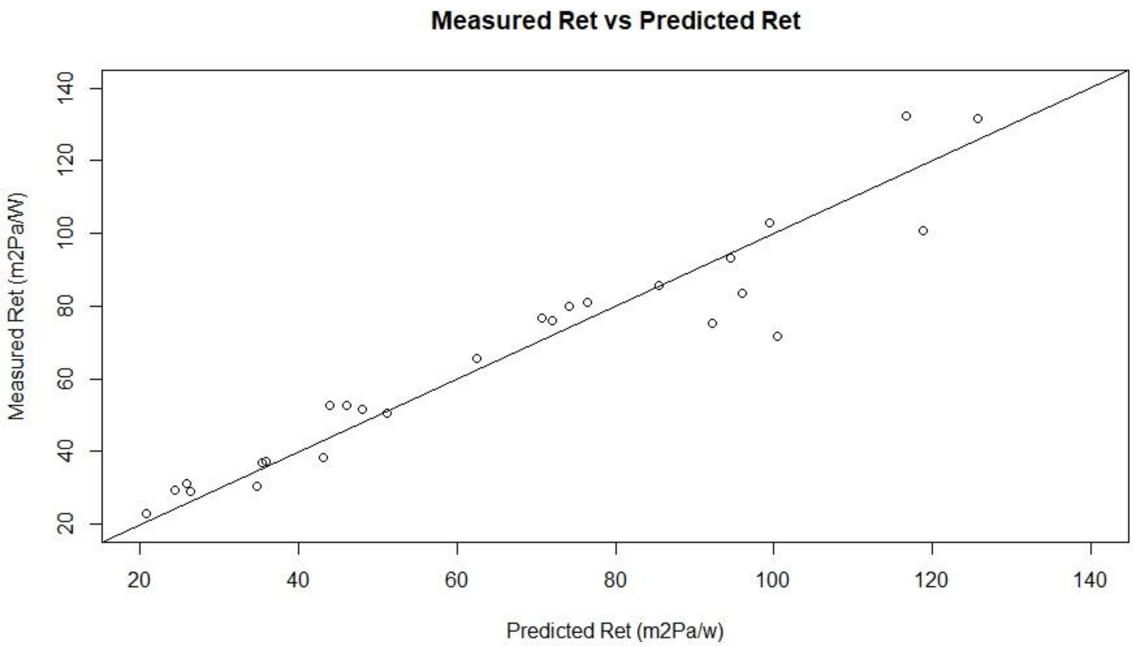

Figure 1. The measured R_{et} value is plotted against the predicted R_{et} values and represented as circles. A 1:1 line visualizes a perfect prediction.

In Figure 1 the measured R_{et} and predicted R_{et} are compared using a 1:1 line as visual aid to detect the outliers. What we can see in this study is that our model predicts well the measured R_{et} of the clothing up to 80-90 R_{et}, then the deviation from the 1:1 line becomes greater. Both ensembles have sets that are more focused on the protection of the worker while also having sets that are more general such as a simple sweater and pants. It appears that the thicker protective clothing introduces higher uncertainties in the model. This indicates that the model provides good results for clothing with relatively normal permeability including the ones with membranes in the outer layers. Linear relationship between the air layer thickness and evaporative resistance was described also by Psikuta et al. (6) for different clothing ensemble sets. None of the systems used impermeable layers which may be of less interest as the R_{et} value for such layers are very high and no sweat evaporation can be expected anyway. The biggest drawback of the current model is that it's only using input of layers on upper body, lower body and head which may be an issue when feet and hands are important.

Conclusions

Our model provides a good prediction of the measured R_{et} values, however, the applicability of the model must be further evaluated using more data and considering what input data is reasonable in a real world application.

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Active heating shirts for workers in cold environments: which combination is more effective?

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Keywords
cold stress, upper arms, rectal temperature, peripheral skin temperature, thermal sensation

Introduction

Recently, active heating garments have been widely worn in industrial fields to prevent cold-related diseases such as hypothermia, frostbite, or non-freezing cold injury (1,2). At the same time, those heating garments are expected to minimize the load of a battery that might affect the mobility of workers. In order to reduce total mass of garments, selective body heating is efficient. In this regard, physiological evaluation on regional body heating strategies has been continuously conducted. However, there are rare studies reporting which body region among the trunk region is most optimal for heating, although it is proven that the trunk heating was more efficient for body temperature regulation under cold stress than the lower body heating. There is still no agreement on whether the upper arms could be included in the trunk body part or the peripheral body part. The purpose of the present study was to investigate the effects of upper arm heating along with upper back or chest heating on thermoregulatory responses while exercising in a cold environment.

Methods

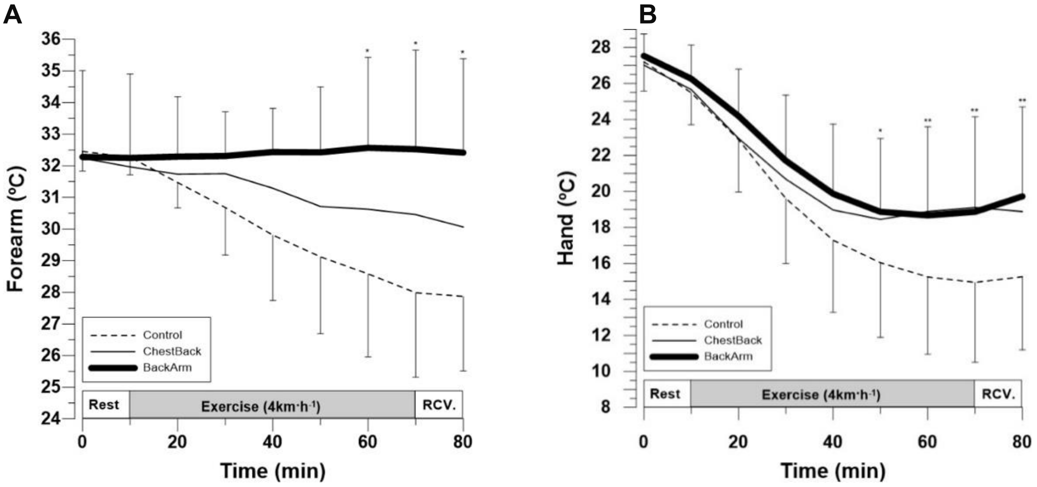
A total of 10 young males participated in the following three experimental conditions: (1) non-heating (Control), (2) heating the chest and upper back (ChestBack), and (3) heating the upper back and upper arms (BackArm). We developed a liquid-perfused shirt, which was designed to allow water to flow into the PVC tubing inside the shirts to the particular body regions (the chest/upper back or upper back/upper arms). The tube surface temperature was about 42°C. A trial consisted of 10-min rest on a chair, followed by 60-min walking at 4 $km \cdot h^{-1}$ on a treadmill, and 10-min recovery in a chair. Subjects wore winter ensemble including a duck-down jacket with/without the active heating shirt. All trials were conducted at a climatic chamber of -9°C air temperature. Throughout the protocol, rectal temperature, skin temperature on nine body regions (forehead, chest, back, abdomen, forearm, hand, thigh, calf, and foot), metabolic rate, total body mass loss, blood pressure, and subjective responses were measured.

Results and discussion

There were no differences in T_{re} during rest, exercise, or recovery among the three conditions. However, the increases in T_{re} from rest to exercise were greater for the both heating conditions than for the Control (P=0.012) without any difference between the two heating conditions (Table 1). This indicates that heating the upper body could be more effective to elevate core body temperatures than non-heating while exercising in cold environments. In particular, we found that forearm temperature was significantly higher for the BackArm condition than the ChestBack condition (Fig. 1 A, P = 0.042). Furthermore, the forearm temperature for the BackArm condition was maintained without any gradual drop throughout the entire exposure, whereas the forearm temperature for the ChestBack condition gradually decreased until the recovery. Even though the hands were directly affected by the cold air as the gloves were not worn, it was observed that the hand temperature dropped relatively gently in ChestBack and BackArm compared to Control. After 32-min exercise, a difference in hand temperature was found between the three conditions (Fig. 1B, P = 0.1). In particular, at the end of the recovery, it was shown that the hand temperature increased by 0.87°C compared to immediately after exercise in BackArm, while it decreased in ChestBack by 0.23°C. During the overall phases, significant differences in metabolic rate between the three conditions were found (P < 0.001 at rest; P = 0.002 during exercise; P = 0.003 in recovery), and the minimum metabolic consumption found in BackArm, followed by ChestBack and Control. Subjects felt less warm and less uncomfortable for the BackArm condition than for the ChestBack condition. The consistency of changes in forearm temperatures and subjective responses is supported by the previous study (3). Taking account that most winter jackets have front-centred closures and frequent movements of the limbs occur causing the pumping effect of clothing, heating the upper arms could be a more efficient strategy than heating the chest. Keeping the forearms warm while working in cold environments would be more effective for the manual workers.

Table 1. Changes in rectal temperature during rest, exercise, and recovery.

	Control	ChestBack	BackArm	P value
REST (10-min)	37.0 ± 0.2	36.9 ± 0.2	36.9 ± 0.2	0.175
EXERCISE (last 3-min)	37.3 ± 0.2	37.4 ± 0.2	37.4 ± 0.2	0.180
RECOVERY (10-min)	37.3 ± 0.2	37.4 ± 0.2	37.4 ± 0.1	0.199
ΔT_{re} (EXERCISE – REST)	0.35 ± 0.18	0.50 ± 0.25	0.54 ± 0.20	0.012



* $P < 0.1$, ** $P < 0.05$

Figure 1. Changes in forearm and hand temperature at an air temperature of -9°C. 'Control', 'ChestBack', and 'BackArm' represent non-heating, heating the chest/upper back, and heating the upper back/upper arms, respectively.

Conclusions

We investigated thermoregulatory effects of body regional heating at 42°C using a liquid-perfused shirt in a cold environment. Warming the back and upper arms was more effective for keeping peripheral skin temperatures warm and minimizing the metabolic consumption, which showed more synergistic effect on improving subjective sensation in cold, compared to the combination of heating the chest and back.

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Sustainable alternatives to fluorinated water repellent protective fabrics

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Keywords
protective fabrics, non-fluorinated durable water repellent (DWR), poly/perfluoroalkyl substances (PFASs)

Introduction
Investigations have been conducted into the usage of protective clothing made from fluorinated durable water-resistant (DWR) materials as a potential source of human exposure to poly/perfluoroalkyl substances (PFASs) (1-3).To avoid exposure to these chemicals, it is desirable to stay away from fluorochemicals when applying topical finishes to protective uniforms. However, transition from short chain fluorinated DWR to a more sustainable alternate chemistry (Fluorine-free) is a complex process, and requires extensive research into several aspects, including chemistry, the application method, toxicity (4), environmental impact, regulatory constraints, analytical difficulties (5-6), and performance demands (7).

Results and discussion
This research focuses on the distinction between polymeric PFAS which are made of repeating units and commonly used as a coating/laminating on fabrics versus non-polymeric PFAS which are individual molecules. The study also examines the difficulties in accurately analyzing volatile and non-volatile PFAS in durable water and oil-repellent treated fabrics. The analytical challenges include limited authentic standards, contamination during sampling, and specialized testing expertise. Using Liquid Chromatography-Mass Spectroscopy, the study analyzes 50 target per/polyfluoroalkyl substances on fabrics. Additionally, the research investigates the effects of transitioning from fluorinated to non-fluorinated DWR fabrics on functionality, performance, and protection for trout gears. The study evaluates the effectiveness of non-fluorinated DWRs such as acrylate waxes, silicone, urethane, and dendrimers against diesel fuel, acid, alcohol, and alkalis. Table 1 shows an example of exchanges in functionality due to the transition from fluorinated to non-fluorinated DWR fabrics.

Table 1. Protection against liquid chemicals on fabric treated with fluorinated and non-fluorinated DWR.

Protection against liquid chemicals (ISO 6530)		Inherent FR fabric	
		C6 DWR	PF ZERO
Acid (Sulfuric acid 30%)	Index of repellency (%)	99.5	99.2
	Index of absorption (%)	1	1.4
	Index of penetration (%)	0.2	0.2
Diesel fuel (O-Xylene)	Index of repellency (%)	94.02	0.7
	Index of absorption (%)	3.8	63.5
	Index of penetration (%)	1.9	32.7
Alkalis (Sodium Hydroxide 10%)	Index of repellency (%)	98.7	98.1
	Index of absorption (%)	1.3	1.2
	Index of penetration (%)	0.2	0.3
Alcohol (Butanol-1)	Index of repellency (%)	94.4	19.3
	Index of absorption (%)	4.9	50.7
	Index of penetration (%)	0.5	28.6

Conclusion
By considering trade-offs such as a lack of diesel fuel repellency, the study aims to provide insight into the benefits and drawbacks of non-fluorinated DWR fabrics and reduce human exposure to PFAS.

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Tailored materials for electromagnetic shielding textile application

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Keywords
electromagnetic shielding, textiles, shielding effectiveness, metal oxides, carbon nanotubes, conductive polymers

Introduction

The continuous development in communication technologies and electronic equipment, such as communication towers, radars, cell phones, wireless equipment, internet, *etc.*, has led to increased exposure to electromagnetic (EM) radiation, particularly in the radiofrequency (RF) range. This type of radiation can cause two major problems: (i) negative impact in the operation of nearby equipment; and (ii) health hazards (1). For example, the latest fifth generation (5G) of wireless Internet technology, whose frequencies can reach up to 300 GHz, has raised concerns about its potential consequences to health and to the environment. A recent report on the 5G health impact sponsored by the European Parliament summarized the current state-of-the-art regarding possible carcinogenic effects or reproductive hazards that have emerged from epidemiological and experimental *in vivo* studies (2). The most striking findings of this study include the positive associations between cell phone use and gliomas (brain tumors) and acoustic neuromas in humans, which have been verified with sufficient evidence in experimental animal studies. Another important finding, also demonstrated with sufficient evidence in both epidemiological and *in vivo* studies, is the correlation between RF radiation and adverse effects on male fertility (*e.g.,* sperm count and viability, DNA integrity, *etc.*). The report concludes that it is extremely urgent to conduct more studies on 5G, especially for higher frequency EM radiation, suggesting solutions such as the creation of technologies that allow its attenuation, methods that reduce exposure, or promoting information campaigns about this technology. EM shielding is a method used to create barriers between EM radiation and the subject to be protected. Metals, such as silver and copper, are the most common materials used for this application. However, metal-based shields have limitations, such as inflexibility, corrosion problems or high weight. As a result, researchers have begun to explore alternative materials such as carbon-based materials, metal oxides, or polymers, which have demonstrated to have favorable properties for EM shielding applications (3).

In this research, commercial materials such as multiwalled carbon nanotubes (MWCNTs), titanium dioxide (TiO_2), iron oxide (Fe_2O_3) and zinc oxide (ZnO) were combined with a conductive polymer to develop composite materials with EM attenuation properties. The obtained composites were then applied in the fabrication of EM shielding textiles.

Methods

EM shielding textiles were prepared in this work using different types of composite materials for comparison of their EM attenuation properties. Three types of pastes were prepared using a conductive polymer as matrix and the following fillers: a) commercial MWCNTs; b) commercial TiO_2 and Fe_2O_3 (TiO_2/Fe_2O_3); c) commercial TiO_2 and ZnO (TiO_2/ZnO). The resulting pastes were applied over 100% cotton knitted fabrics through the knife-over-roll coating technique, followed by drying and curing. The textiles present a uniform and continuous coating. The thickness of the textile substrate and the coated textile samples were measured using a profilometer. The measurements were taken from various parts of the samples and an average value was calculated. The EMI shielding properties of smaller (5 x 5 cm) pieces of the textiles created were evaluated. The conjoined rectangular waveguides method was used to measure the EM shielding ability of the coated textiles in the frequency range of 5.8 to 18 GHz. The textiles were placed inside the waveguide section, and the shielding effectiveness (SE), given in decibel (dB), was measured using a vector network analyzer.

Results and discussion

The coating method produced functional textiles with homogeneous and smooth coatings. The SE results are shown in Table 1. The most promising formulation in terms of shielding ability and application was the one containing TiO_2 and Fe_2O_3. TiO_2 has one of the highest electrical conductivities in semiconductors and a high refractive index, making it effective in absorbing and reflecting EM waves, reducing their intensity and minimizing their effect on EM shielding applications. Fe_2O_3 has a high magnetic permeability, making it effective in absorbing and scattering EM radiation in the lower frequency range. The combination of TiO_2 and Fe_2O_3 in a composite material has shown a synergistic effect, providing enhanced EM shielding performance over the individual materials and the other testes materials. Thus, the resulting textile coated with that paste achieved an average SE of 33.7 ± 1.1 dB in the measured band frequency for a coating thickness of 89 µm. Furthermore, it also had the best result when normalized by the coating thickness (378 dB mm^{-1}), meaning that with this formulation it is possible to achieve better attenuation values with thinner coatings. In professional applications like protective garments for the telecommunication sector, SE values 20 - 30 dB are considered fair, while values >30 dB are moderate (4). Although the developed shields are still useful for professional applications, they may not be as effective as those for general applications. However, the textiles are highly suitable for general applications, including protective clothing for general wear, with SE values >30 dB.

Table 1. EM shielding properties of the functional textiles.

EM Shielding Textile	Coating Thickness (µm)	SE (dB)	SE/t (dB mm^{-1})
MWCNTs	263 ± 49.0	28.5 ± 1.5	108
TiO_2/Fe_2O_3	89 ± 13.4	33.7 ± 1.1	378
TiO_2/ZnO	218 ± 16.6	22.6 ± 0.9	103

Conclusions

In conclusion, a textile shield with a SE of above 30 dB was obtained through the fabric coating with a formulation containing TiO_2 and Fe_2O_3. This result corresponds to a classification of excellent for shielding textiles suitable for general use (4). Optimal features such as flexibility, lightweight and good homogeneity were obtained with these formulations through a simple coating application process, making it suitable for wearable applications. These textiles can be used for various purposes such as clothing for general wear, sportswear and maternity wear.

Acknowledgments

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User input for PPE for pesticide operators: a global framework for data collection

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Keywords
protective clothing, user input, garment development, database, pesticide operators

Introduction

The determination of operator safety when handling and applying pesticides is an important aspect for pesticide registration. Risk assessment to determine if operators can safely apply the pesticide product is usually conducted in countries with a regulatory infrastructure to support the relatively complex process. The FAO Pesticide Registration Toolkit was developed to support regulators from countries with limited resources is enabling countries to conduct risk assessments for national/regional pesticide registration processes (1).

Personal Protective Equipment (PPE), considered the last line of defence, is used to mitigate risk. Cost, comfort, availability, and PPE quality are some of the major constraints for PPE usage in Low- and Middle-Income Countries (LMICs) (2). ISO 27065, an international standard for PPE for pesticide operators and re-entry workers, provides a mechanism to defining terms and minimum requirements for whole and partial body garments (3). PPE equivalencies based on operator exposure studies enable Level C1 garments to be used as the base requirement and C3 partial-body garments for additional protection.

A partnership approach allows stakeholders from several regions of the world to work collectively in the development of risk assessment and mitigation system for hand-held application scenarios commonly used in many LMIC's (4). As part of this innovative initiative, stakeholders from regulatory agencies, pesticide industry, universities, testing and certification laboratories, and fabric and garment manufacturers are working collectively to address constraints such as availability and quality. The goal is to use expertise and best practices available globally to manufacture protective clothing "locally". Kenya is the case study country where "local" fabric was tested and fabric selected for manufacture of certified ISO 27065 C1 protective clothing.

Methodology

As user acceptance is crucial for adoption of PPE, a grassroots approach was used to engage potential users as part of the discussion. Factors such as culturally acceptable garment type, colour, availability, cost, and mechanism of distribution were considered in the two-step process for C1 garments and three-step process for C3 garments. This presentation will focus on the two-step process for C1 garments.

Step 1: Obtain information from individuals working closely with the operators on the cultural norm for garment type and features. Group Leaders who will collect data from the users in a face-to-face focus group meeting are part of this group. Information collected in Step 1 is used for development of 1/3rd scale prototypes for Step 2.

It is important that Group Leaders are trained on how to conduct and collect data prior to the focus group meetings. This will help to ensure a process to obtain consistent data from diverse sources. In this training, Group leaders will be provided with training materials, talking points and a check-list of what is needed (e.g. translated consent forms, print out of surveys etc).

Step 2: Group Leaders will meet with farmers/operators in informal, small group settings, to obtain user input. Consent forms that follow applicable regulations will be translated into the local language will be covered as part of the initial introduction. Terminology used in questionnaire and group discussion will be explained using garment prototypes. In addition, a poster with sketches of the respective features and colour swatches will be on display.

- ***Step 2a:*** A standardized questionnaire will be completed by the participants prior to group discussion. Demographic and information regarding spray application is included in Part 1; user preference for garment type and features are included in Part 2. Note: Based on literacy level, a note taker may be required to read out the questions and record the answers.
- ***Step 2b:*** Group discussion will provide an opportunity for the Group Leader to facilitate discussion on Part 2 of the questionnaire. Each question on garment type and features will be discussed collectively taking into consideration factors such as cost, protection, comfort, ease of donning and doffing. The note taker will enter the group response and reasons for selection of the garment type, colour and the respective features. Based on the discussion, the group will collectively "design" garment to be proposed

for consideration As a last step, the group will review manufacturing cost provided by the local PPE manufacturer with the option to redesign the garment if warranted..

Project Outcomes

User input for the development of PPE for pesticide operator is often obtained on a limited basis. A multidisciplinary team, comprised of individuals from several countries and wide range of expertise (functional design, garment manufacturing, global sustainability, research, understanding of cultural norms and preferences) facilitated the development of the framework. The user input will support the development of C1 PPE produced by local manufacturers using fabric manufactured in Kenya. The framework will facilitate development of a global database to collect user acceptance data for PPE for pesticide operators. Plans for 2023 include data collection in conjunction with ongoing farmer training program in Brazil and four additional African countries. Although the initial planning for framework development required extra effort, it reduces the effort required in the future.

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Wildland firefighting and other operational conditions

Health management of firefighters during natural wild fires. a global and integrated approach

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Keywords
firefighters, wildfire, health, operational support, heatstroke, PPE

Introduction

Created in 1986, the main missions of the Health Services of the Firefighters in France are health at work, support in operations, health and safety, participation in professional training, medical and first aid equipment and participation to emergency rescue. Occupational health and operational support, closely linked, are the main missions. The Gard district is particularly exposed to natural risks such as forest fires (Figure 1) and floods.

As such, the health service, perfectly integrated into the global management and command chains, has developed a global strategy to support first responders, with more specific expertise for fires in natural areas.

Figure 1. Typical incident for the Gard district.

Supporting activities

The Health Services support health at work for firefighters. Their activities are focused on:

> Medical selection of personnel, with a particular focus on cardiovascular risk, guaranteeing a level of operational response.
> Following the firefighter's operational task throughout the engagement, with specific focus on:
  - physical fitness (in connection with the conditions and durations of intervention),
  - assessment and control of risk factors: weight, dyslipidaemia, glycaemic balance, etc.
  - detection of pathologies, especially on cardiovascular and musculoskeletal systems, with specialized orientation in the slightest doubt.
> Research work, studies and analyses on tolerance of protective clothing, heatstroke, smoke toxicity, research on high-risk occupations.

Supporting teams

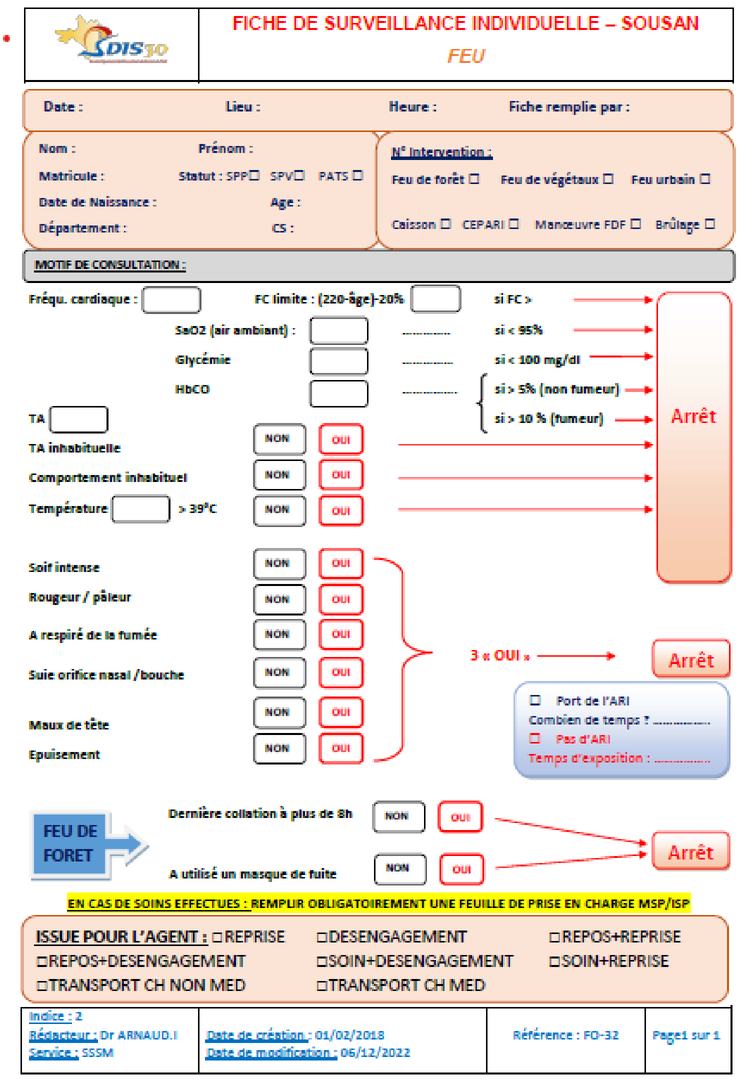
For health support there are predefined commitment levels (e.g. rescuers, nurses, medicals doctors) according to the size of the interventions. The health teams are fully equipped (vehicles, dedicated and specific equipment), have a good education (graduation in emergency medicine) and are well trained (tactical simulation and exercises with the command teams).

Field work

In large incident a rehab area are established adjacent to command posts where personnel requiring treatment are welcomed, registered, supported and treated for or with specific clinical evaluation protocols (decision support sheets) , nursing and medical care protocols. Extraction procedures are prepared for the most serious injuries (cardiorespiratory arrest, multiple trauma, etc.) where medical teams are transported to safe environments. Further, on health coordination in command posts, according to the global management of the fire are managed.

Preventive measures

For health and safety a selection for proper choice of personal protective equipment, especially for the their body impact assessment, supervision of food support and hydration on rehabilitations areas are prepared. Predefined hygiene rules, taking into account the duration of the interventions are settled. Feedback is gathered for improving preventive measures (Figure 2).



FICHE DE SURVEILLANCE INDIVIDUELLE – SOUSAN
FEU

Date : Lieu : Heure : Fiche remplie par :

Nom : Prénom :
Matricule : Statut : SPP☐ SPV☐ PATS ☐
Date de Naissance : Age :
Département : CS :

N° Intervention :
Feu de forêt ☐ Feu de végétaux ☐ Feu urbain ☐
Caisson ☐ CEPARI ☐ Manœuvre FDF ☐ Brûlage ☐

MOTIF DE CONSULTATION :

Fréqu. cardiaque : FC limite : (220-âge)-20% si FC >
SaO2 (air ambiant) : .... si < 95%
Glycémie .... si < 100 mg/dl
HbCO .... si > 5% (non fumeur) si > 10 % (fumeur)
TA
TA inhabituelle NON OUI
Comportement inhabituel NON OUI
Température > 39°C NON OUI
Arrêt

Soif intense NON OUI
Rougeur / pâleur NON OUI
A respiré de la fumée NON OUI
Suie orifice nasal / bouche NON OUI
Maux de tête NON OUI
Epuisement NON OUI
3 « OUI » → Arrêt

☐ Port de l'ARI
Combien de temps ? ....
☐ Pas d'ARI
Temps d'exposition : ....

FEU DE FORET
Dernière collation à plus de 8h NON OUI
A utilisé un masque de fuite NON OUI
Arrêt

EN CAS DE SOINS EFFECTUES : REMPLIR OBLIGATOIREMENT UNE FEUILLE DE PRISE EN CHARGE MSP/ISP

ISSUE POUR L'AGENT : ☐REPRISE ☐DESENGAGEMENT ☐REPOS+REPRISE
☐REPOS+DESENGAGEMENT ☐SOIN+DESENGAGEMENT ☐SOIN+REPRISE
☐TRANSPORT CH NON MED ☐TRANSPORT CH MED

Indice : 2
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Figure 2. Feedback form.

Registered injuries

The most common injuries encountered in the field are:

> Heatstroke of all types and levels of severity,

> Cardiovascular pathologies : chest pain, myocardial infarction (one per year in average), cardiac arrest, etc.

> Burns (established partnership with a university hospital center for initial treatment and following of the injuries),

> Traumatology of various types and severity.

The medical data of each patient treated is then analysed as part of our global experience, feedback for increasing the level of practices and securing procedures.

Conclusions

Perfectly integrated with the other services of our public institution, the health service fully participates in the policy of fighting against fires in natural spaces with the risks and consequences that are specific to it. At this time, our major fear remains the cardiovascular risk, generated by heat stress caused by the conjunction of the intervention conditions (heat, draught), the duration of the interventions (sometimes several hours), and the personal protective equipment whose wearing must be adapted to the circumstances and the risks.

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From urban structural firefighting to wildland firefighting – a Northwest European journey

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Keywords
discomfort, comfort stress, wildland firefighting

Abstract
The influence of climate change on our environment is now well documented. The mean global land temperature has risen substantially. Europe is even warming faster than the global average. The mean annual temperature over European land areas in the last decade was 1.94 to 2.01°C warmer than during the pre-industrial period.

Fires in the natural environment are dictated by the two parameters - meteorological conditions and (the availability of) vegetation. Climate change influences both, resulting in more frequent fires and more severe fire behaviour. This results in a change of fire regimes all over the world.

For Northwest Europe this results in a substantial fire regime shift. Vegetation fires will shift from infrequent fires and mild fire behaviour, which are easily managed by the urban firefighting force currently tasked also with wildfire management, to a more frequent fires and higher fire intensities, which need a more specialized approach.

This impacts not only the education and level of expert knowledge within our fire brigades, but also different tools and PPE. One of the most visible changes will be the seen in PPE. In the Netherlands we are trying to prepare for the future with an integral approach, where Research, Prevention and smart Suppression are intertwined and will be developed simultaneously.

The regular PPE for the firefighters is in the line of EN 469 (1). This standard concerns for interior attack of structural fire's. These indoor spaces incidents have higher temperatures because of the "closed box", while having also a shorter timeline for control and extinguishing.

Fire control and extinguishing of wildland fires concern predominantly long-term deployments with at least medium level of physical effort. This means that the PPE used for basic firefighting is commonly not suitable. In addition, we see different needs for protection depending on terrain and vegetation: inhospitable areas, heavy forestation and heather- and peat moorland.

The current wildfire clothing was developed in countries that had frequent wildfires in the past. We suspect that the clothing can be better and more specialized providing less comfort-stress in the different natural conditions as outlined above.

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Higher standardised test performance of PPE materials does not automatically lead to higher safety

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Keywords
performance, firefighters' PPE, risk, insulation, core temperature, heat stress, false safety

Background

Firefighters can carry out their work in extreme conditions thanks to high-quality personal protective equipment (PPE). The development of PPE has taken off since the 1980s. Partly due to the continuous development of science, improvement of techniques, high-quality raw materials and the further development of production. Also the attention, mandatory or not, for occupational safety but also the development of standardisation institutions such as ISO (global) and CEN (EU) have contributed to higher safety levels.

The market is constantly looking for new arguments to create new sales in addition to further development. Through participation in standardisation committees, the market influences PPE because these standardisation committees determine the design of tests and minimum performance levels. The standardisation committees thus have a decisive influence on development in the market.

The test performance of textiles in particular is mainly performed with static tests on the material. With this, no or insufficient attention is paid to the performance of the products as they are used in practice with variables such as design and composition, fit (right size) and in combination with (under)clothing and other PPE.

If the protective insulating value of the clothing is higher, for example against environmental influences, it will also seal off the body further from the environment. As a result, the body cannot or cannot sufficiently dissipate its heat and thus the core temperature, especially during medium to heavy exercise, can rise to critical values relatively quickly.

The higher level of protection, resulting from higher material technical performances, has the disadvantage that the impact on the wearer is not or not sufficiently considered. There is currently an attempt within the ISO standards for firefighters' clothing to increase heat testing from 180°C to 260°C, and the question is whether resistance to higher temperatures contributes to safer intervention or makes it more unsafe but?

Work is currently underway within ISO (1) to define the minimum protection for firefighters' PPE and taking the link to NFPA guidelines (4) test temperatures of 260 °C as a basis. With the exception of the Hoshke table (5) from a NIOSH project, no valid data has been provided on this so far.

In Germany, after the accidents in 2009 and 2010, the various research projects (6, 7 and 8) on the thermal stress of respiratory protection equipment in an internal attack were started, including the field tests and investigations. The fact was that a PPE design with a resistance of 180°C provides sufficient protection. To this end, the German and Dutch experts on the CEN standardisation committees sought to include this in the revision of the relevant standards (2) to be taken into account.

Accident statistics also argue that the burns suffered by firefighters using PPE according to EN standards are no reason to increase the minimum requirements. The consequence would be that PPE according to ISO standards would become heavier (and more expensive) and ultimately also increase the physiological stress of the wearer(s) in terms of fatigue, movement restriction and possibly visibility, as well as heat stress.

Discussion

The fire brigade in Europe predominantly uses 6-litre cylinders for structural firefighting, which means that, due to the consumption of breathing air, in combination with high physical exertion and ambient temperature (air) 50°C to 150 °C it is possible to stay indoors for 20-25 minutes. A longer stay is also not desirable because there is too great a chance that the firefighter's core temperature will rise above the critical limit of 38°C (3). The Hoschke table defines this as "hazardous conditions" where the radiation heat flux is between 1 and 10 kW/m2. A longer stay without cooling capability is risky and may even be dangerous (10). By applying alternating firefighters and thorough tactics, a longer stay is not necessary in most deployments. The German study (6) shows that in regular deployments, temperatures are only very briefly higher (maximum 2 minutes) because firefighters always act under cover of a fire hose. The question is therefore why should all firefighting clothing for structural firefighting then meet a higher level? After all, there are no known (11) accidents from the past 10 years in which the current 180°C has proved inadequate.

The effect of isolating the wearer from the environment is that it can no longer rely on what the senses perceive and only cognitively perceive and react. Although this is not desirable, with targeted firefighter education and training, deployment in an extreme environment like a house fire with dangers can be justified and accepted. One of the effects of (too) high core temperatures is that cognitive ability is impaired which can impair rational thinking. In an environment where there are constantly changing dangers and emergency workers depend on each other, PPE should not only provide protection but also prevent (12) the wearer from becoming a danger to himself and others. The further and better isolation of the wearer from the environment further isolates the wearer's senses from the environment they are in. The lack of sensory perception makes the wearer rely on visual perceptions. A higher insulating capacity will also cause the clothing to take longer to let heat through. The danger is that one then stays in it too long but e clothing also heats up further and the energy of a higher temperature impact in the clothing will lead to a longer and more intense release. This makes the impact even more detrimental and instead of improving safety it constitutes an increase in risk.

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When water goes up in smoke, experimental research into the effect of the 3D pulse method and the arc method on smoke cooling

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Keywords
smoke cooling, steam burns, steam, arc method, 3D pulse method.

Introduction

Opinions differ when it comes to the question of how to approach the seat of a fire that cannot be reached directly with the extinguishing agent, making it necessary for firefighters to progress through hot smoke. In the Netherlands, the '3D pulse method' is used as a smoke cooling technique. Instructors have noticed that this method is difficult to learn, requires a lot of practice and training and is rarely performed correctly. There is also evidence that the pulse method is seldom applied in practice. More information on other possible smoke cooling methods which are also effective and which are easier to learn is also required. Consequently, our research compares the 3D pulse method used in the Netherlands to the arc method used in the United States of America. These methods are compared for both high pressure and low pressure systems. Because some Dutch fire brigades are equipped with CAFS OneSeven (Compressed Air Foam System), CAFS has been included in this research as well (1, 2). Because globally in de FRS community there is a lot of discussion about steam production and reported discomfort and heat burns of Firefighters we also measured temperatures at different levels and interviewed the firefighters about their experiences with the various applied methods.

Methods

The different methods were only applied to a scenario with a dynamic smoke layer.

The research was conducted in a L-shaped brick building. The long part of the L-shape consisting of a 2-metre wide, 2.5 metre high and 20-metre long corridor. The fire room was located in the short part of the L-shape. The fire load was a major fire in a living room (6 – 8 MW). The firefighters used the protective clothing of their own region.

Various parameters were measured at different locations and/or heights inside and outside the building during the experiments. These parameters were the temperature, radiation, gas concentrations and footage inside and outside. The fire attack team's subjective perception was also measured by means of a questionnaire immediately after the attack.

Results and discussion

An important aspect of the design of these experiments was the repeatability of the starting conditions. The measurement results have shown that in general, the dispersion in results was limited (about 10 %), indicating good reproducibility of the conditions.

The results of the arc method are more positive than those of the 3D pulse method, both as regards cooling along the height and length of the corridor, and as regards forwards and backwards cooling (Figure 1). The results of the arc method are also more consistent which seems to indicate that this method is easier to carry out. The average scores of subjective perception of thermoregulation, discomfort and effort show that the experiments were not unduly strenuous for the attack team. In the Netherlands (3, 4), there is discussion about the formation of steam during smoke cooling which causes discomfort for the fire fighters. However, in our experiments there was no steam mentioned. Our hypothesis is that the steam is discharged as a result of the dynamic smoke layer. The dissipation of the energy is important because otherwise the gaseous water will pass through the protective clothing, condense there and thus release energy.

The deployment of fire attack teams will always have negative consequences for casualties (5, 6) due to an increase in CO values, regardless of the fire extinguishing system or method used, as compared to baseline. Life-threatening or even fatal situations arise for vulnerable and highly vulnerable casualties further down the corridor. No life-threatening situations arise for casualties in the general group, with one exception. Both baseline measurements, i.e. where no fire attack took place, showed that it took longer for a life-threatening situation to arise.

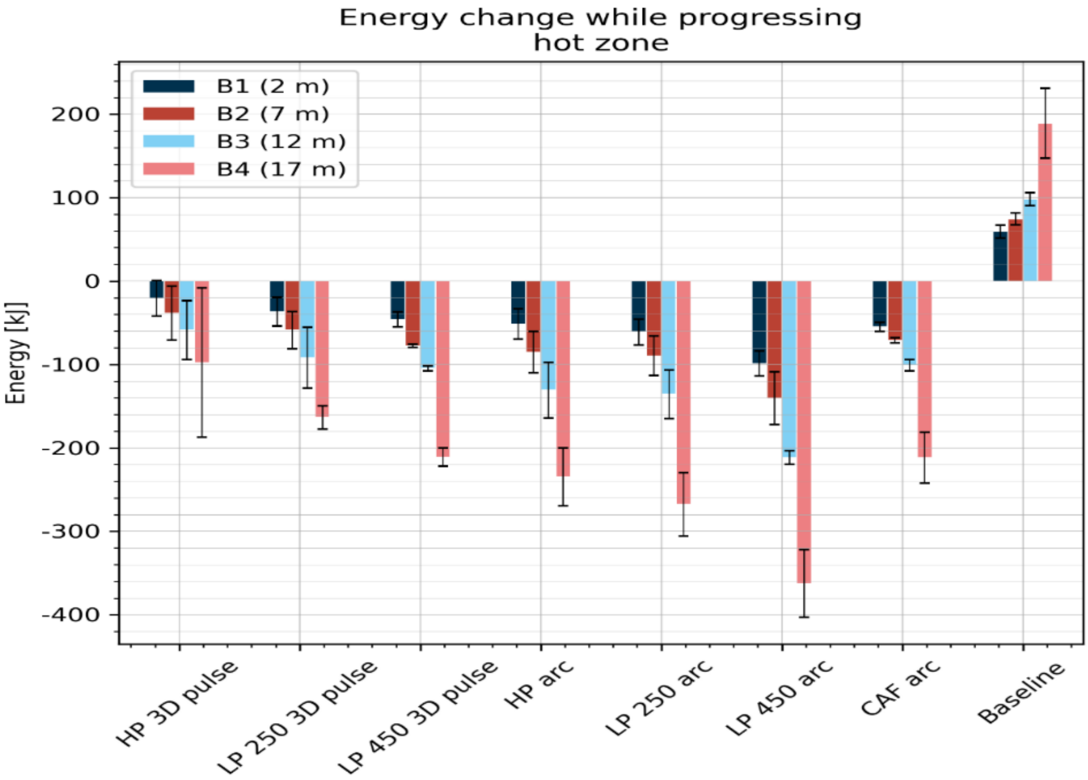

Figure 1. Energy change while progressing hot zone.

Conclusions

Based on this research, it can be concluded that both the arc method and the 3D method are effective methods to cool smoke gases, but that the arc method provides more cooling, and is easier to learn and carry out. No unsafe situations for fire service personnel in any used protective clothing ensembles, either measured or reported, arose during the experiments. Conditions for potential casualties worsened by the use of the methods and extinguishing systems researched for smoke cooling. This might lead to life-threatening or fatal situations for vulnerable and highly vulnerable people. In general, the arc method worsened these conditions less than the 3D pulse method, specifically in the front section of the corridor.

Firefighters did not experience significant discomfort when applying higher flow rates or the straight stream method, nor did we observed excessive steam or steam burns.

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Ergonomic testing and human studies of clothing systems

A new testprotocol for ergonomic evaluation of firefighters' protective clothing

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Keywords
protective clothing, turn-out gear, firefighters, standards, ergonomics, freedom of movement, thermal comfort, heat protection.

Introduction

In order to qualify protective firefighting clothing in the Netherlands, a governmental program was started in the 1980s to quantify turn-out gear based on ergonomics. Since the publication of the 1st European standard for protective clothing for firefighters (1), it is possible to set minimum requirements for the clothing materials for turn-out gear. However, it is also important that, in addition to these material requirements, the turn-out gear is assessed for functionality by means of a reliable and reproducible ergonomic test battery. In the previously developed test battery, a number of clothing functionalities were discussed, such as (thermal) comfort, heat protection, freedom of movement and water protection (2) as the most important ones. Despite our efforts, these requirements are still missing in the current EN469:2020 (3), although the European Regulation (4) is clear about it in Annex II: '*Ergonomics; PPE must be designed and manufactured so that, in the foreseeable conditions of use for which it is intended, the user can perform the risk-related activity normally whilst enjoying appropriate protection of the highest level possible*'. For that reason most fire brigades in the Netherlands still use ergonomic testing as part of their turn-out gear procurement processes, but are lacking the skills for a scientific approach. There is no clear guidance for them to set up a methodological test procedure for selecting the best firefighter garments for their purpose. That is why we were asked to describe a clear protocol for ergonomic testing of protective clothing for firefighters with the aim that all fire services can carry out practical tests with end-users in the same standardized and reproducible manner.

Process

Like all protective clothing, protective clothing for firefighters should be functional, comfortable and should not hinder them in their tasks. For firefighters this is even more important than for other professions, because the clothing can be a matter of life or death. These aspects should be covered in an (ergonomic) evaluation of the clothing before purchasing the clothing. In a tender, this is done partly through a written round in which it is checked whether the clothing meets the applicable international standards and legislation, but partly the clothing is tested in (simulated) practice conditions with test subjects or a manikin. Most of the fire services use a physical fitness track for determining hindrance of the clothing and they do some exercises in smoke diving training facility to test the impact and protection of the clothing. Afterwards the test persons have to fill in a questionnaire to rank the tested protective clothing. Conditions are not standardized, order of wearing is mostly not randomized and results are subjective opinions about the clothing.

Based on this, previous work on ergonomics was the starting point (2), but also the recently developed standards on ergonomics and compatibility of personal protective equipment (5, 6). In consultation with a representative group of people from the fire services we decided that (physiological) impact and hindrance of the clothing must be measured as well as the protection against heat. Besides optional tests on water and cold protection should be described. The tests should be familiar for firefighters in the field, but must be reproducible and reliable too. The format of (inter)national standards was taken for this guidance document.

Test proposal and discussion

The ergonomic test protocol (7) consists of several parts and is intended to determine the performance of the (new) turn-out gear and to determine the degree of discomfort as a result of wearing the gear. A comparative test (new clothing is compared with each other) or a benchmark test (new clothing is compared with reference clothing) will be carried out under controlled conditions.

For freedom of movement tests, a circuit partly based on the physical fitness track for firefighters in the Netherlands (PPMO circuit[1]) has to be carried out (Figure 1).

[1] https://www.brandweernederland.nl/wp-content/uploads/sites/2/2021/12/schema_ppmo_brandbestrijdingstest_2014-01.pdf

14		**'Victim' dragging** Drag a manikin back and forth over a distance of 10 meters on the floor in Rautek grip as quickly as possible. In the middle the manikin has to be dragged over an obstacle.	Determining the hindrance of the clothing in situations where victims have to be rescued from a building	Time (s)

Figure 1. Item 14 of the freedom of movement tests; an example.

The (relative) loss of performance is measured by the following formula: $(1-(\text{time reference}_{clothing}/\text{time test}_{clothing}))*100$ (%). The maximum allowed loss of performance is 10 % in case of testing against an unhindered reference clothing set. Afterwards test persons have also to fill in a questionnaire with standardized neutral questions about the clothing to collect subjective information.

Thermal comfort of the clothing is measured in a small room with a heat radiation (infrared) panel in which test persons are walking around during a period of 20 minutes exposed to an average radiation intensity of 1 - 4 kW/m^2. Core and skin-temperatures are measured to calculate the heat store in the body by: $(0.8\Delta T_{core}+0.2\Delta T_{skin})*3{,}48$ in J/g body mass (2). The limit value for heat storage is 8 J/g body mass (8). Afterwards subjective ratings of temperature, humidity, comfort and perceived exertion are given and a questionnaire is filled in.

Heat protection is measured in front of a heat radiation (infrared) panel exposed for a maximum of 2 minutes to a radiation intensity of 7kW/m^2. Measures are time to withdrawal or a skin temperature reaching 43 ºC. Again afterwards subjective ratings of temperature are given and a questionnaire is filled in.

Also optional tests for water and cold protection are described in the guideline, but are not described here.

Final remarks

As the proposed test protocol is not yet approved by the Board of Fire Commanders, there is no obligation for using the protocol and we are not able to draw conclusions about it. The expectation is that in 2023 the first fire services will do pilots with the new protocol supported by NIPV. Results from the pilots must lead to an evaluation of the proposed protocol leading to possible improvements to make it a workable protocol for the fire services in the Netherlands. Also a regular review of the protocol is foreseen.

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(Psycho)physiological effects of wearing taskspecific protective clothing for wildland firefighters

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Keywords
wildland firefighting; protective clothing; (psycho)physiological responses, thermal impact, heat storage

Introduction

Wildland firefighting (WFF) can be considered as the physically most demanding job of all firefighting tasks. It is well documented that wildland firefighters are exposed to a wide variety of aspects that make their work hard; physically demanding activities, extreme climatological (heat, solar radiation etc.) and environmental (rough terrain, vegetation, etc.) conditions while wearing personal protective clothing and equipment (PPE) (1-3). The combination of these aspects may lead to both health risks and operational ineffectiveness. One of the conclusions of the evaluation of a, for Dutch standards, large wildfire that lasted multiple days under strenuous conditions pointed out that a discrepancy between the WFF-tasks and the worn PPE may have led to unacceptable health risks (e.g., exertional heat illness and fatigue) and ineffective performance. To mitigate these risks, a project was set up to investigate the effect of newly designed task specific protective clothing for wildland firefighters on body heat storage and perceived exertion.

Methods

Twelve experienced wildland firefighters (36,9 ± 9,3 yrs; 1,80 ± 0,09 m; 82,3 ± 13,3 kg) completed a simulation circuit that reflected realistic WFF-tasks such as 'rakehoe work', 'lateral hose repositioning' and 'blackout hose work' (4).

The circuit was completed three times and each time in a different protective clothing ensemble: a traditionally during WFF in The Netherlands worn EN469 bunker gear (EN469), and two newly designed task specific bunker gear manufactured from innovative fabrics, namely TenCate Tecasafe® Plus-XL 9240 (TS240) and TenCate Tecasafe® Plus-XL 9300 (TS300).

As primary physiological measure, body heat storage (BHS) was calculated using Parsons' equation (5) [$BHS = (0{,}8 \times \Delta T_{core}) + (0{,}2 \times \Delta T_{skin}) \times 3{,}48$]. T_{core} was measured with an ingestible GI-pill (CorTemp, HQ Inc., Palmetto, FL), while T_{skin} was derived from measurements with iButtons (Maxim Integrated Products, Sunnyvale, CA, USA, type DS1922-T) on four body sites (chest, upper arm, upper leg and calf) using Ramanathan's equation (6) [$T_{skin} = (0{,}3 \times T_{chest}) + (0{,}3 \times T_{upper\ arm}) + (0{,}2 \times T_{upper\ leg}) + (0{,}2 \times T_{calf})$].

Pre-, mid-, and post-trial Rating of Perceived Exertion (6 to 20 RPE-scale), Thermal Sensation (-10 to +10 TS-scale) and Humidity Sensation (-9 to +4 HS-scale) were registered.

Effects of wearing the three different PPE-configurations were determined by a univariate ANOVA. A $p<0{,}05$ was considered as a statistically significant effect.

Results

Figure 1 shows the results of Heat storage in and subjective responses of the test persons. For all variables a significant effect was found between EN469 on one side and both newly designed wildland gear on the other side.

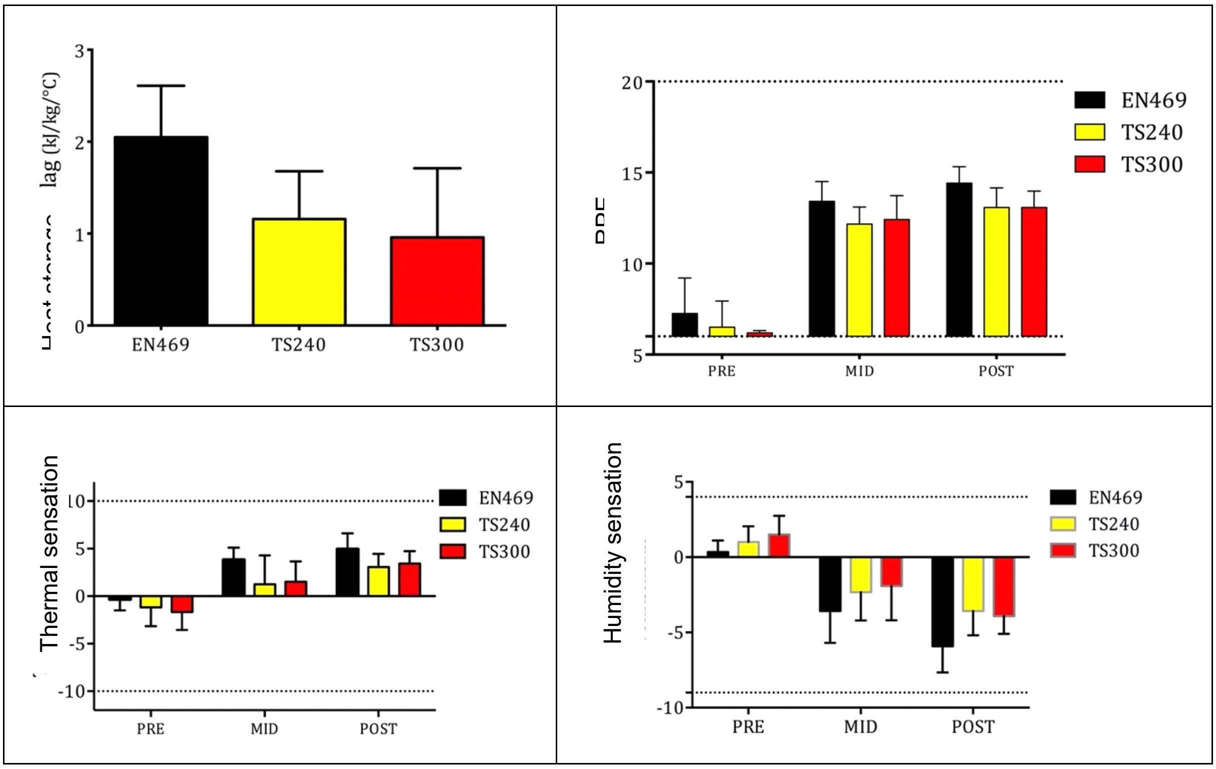

Figure 1. Heat storage in and subjective responses of the test persons. Dashed lines in the RPE, TS and WP represent the range of the scale.

Conclusions

Both body heat storage and perceived measures were significantly higher while wearing EN469 protective clothing than while wearing the newly designed task specific protective clothing. Subsequently, wearing the latter will reduce the risk of heat related problems and will probably also contribute to a greater operational effectiveness.

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Evaluation female firefighter anthropometrics for improved mobility and design in personal protective clothing for the United States fire service

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Keywords
female firefighter, anthropometrics, personal protective equipment, functional design, mobility

Background and Aims
There is a lack of available and properly designed personal protective clothing (PPC) for females in the fire services which can lead to an increased risk of onsite injury, reduction in mobility, and poor wear comfort due to improper fit (1). Gaps in the optimal functional design and mobility for PPC could stem from the lack of anthropometric data on the female firefighter. This study's aim was 1) to implement innovative technology to body scan US female firefighters to develop the first ever female firefighter specific anthropometric database and 2) analyze the anthropometric data and compare it to current sizing requirements in National Fire Protection Association (NFPA) standards.

Introduction
In the United States, 9% of the fire service is comprised of female firefighters with this percentage continuing to rise (2). As more females join the fire services, the importance of donning personal protective equipment (PPE) that appropriately fits the female firefighter's body form is significant; especially given the design differences between structural and wildland turnout suits. Previous research has shown that 80% of the female firefighter population experiences issues with their ill-fitting PPE, a rate four times greater than self-reported male firefighters – this in turn leads to a 33% greater risk of injury for female firefighters (3-7). Often female turnout coats and pants are simplified, and shorter versions templated from male patterns. This approach creates wide, voluminous openings in the sleeve cuff and oversized collars in the jacket, which has increased risk of exposure of hazardous materials (8). Currently, there is no US female firefighter anthropometric database that PPC manufacturers and designers can use to support product development for female specific clothing and gear. It is this study's aim to provide a database that is accessible and will aid in improvements related to the fit, function, and protection of female personal protection clothing.

Methodology
Utilizing a novel approach to collecting body measurements, this research used three-dimensional (3D) mobile scanning capabilities and a developed standardized protocol, from which 189 female firefighters were scanned, and anthropometric data was collected to develop the first ever US female firefighter database. Select body measurements from the database were then analyzed and compared to the current NFPA standards' sizing requirements for both structural (NFPA 1971 *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*) and wildland firefighting (NFPA 1977 *Standard on Protective Clothing and Equipment for Wildland Fire Fighting and Urban Interface Fire Fighting*). Descriptive statistical analysis was performed to assist in the comparative analysis.

Results
When examining and comparing the collected anthropometric data to the NFPA 1971 and 1977 standards' sizing requirements, it was found that the minimum size requirements for wildland protective clothing are much larger than those for structural turnouts, except in the waist. In addition, a large percentage of the collected anthropometric data was found to be outside the required size ranges outlined in both standards. For instance, 31% of the females scanned in this study had chest circumferences smaller than the minimum NFPA 1977 size extra small (XS) requirement. For structural firefighting turnout gear, the analysis showed 23.5% of female firefighters measured larger in the waist than the largest female specific sizing requirement for the turnout pant. This is just one of many statistical examples highlighting the discrepancies identified by this comparison between the NFPA standard sizing requirements and the actual body measurements of US female firefighters.

Discussion
It is important to note that it is a common occurrence for a female firefighter to be issued both a structural turnout coat and pants and wildland shirt and pants depending on their geographical location and fire agency. In fact, findings related to this scope of research found that 39% of US female firefighters perform duties for both structural and wildland firefighting. It was also found that the NFPA 1977 standard did not have male and female specific sizing for wildland shirts, meaning that the size ranges applied to both genders; therefore, indicating that a large portion of female firefighters are wearing shirts that are much too large for their body.

Figure 1. Example of 3D mobile technology used.

Table 1. NFPA 1977 Wildland Shirt Sizing Requirement Analysis.

Measurement	NFPA 1977 Range	Participant Average	Participant Median	Participant Mode	Participant Min	Participant Max
Collar Length/ Circumference	**37.5**-50cm	**36.7cm+**	**36.3cm+**	**37.2cm+**	**31.8cm+**	43cm
Front Length	63-**75.5**cm	74cm	74cm	74.2cm	65.8cm	**82.8cm+**
Sleeve Cuff/ Wrist Circ.	**30.5**-37cm	**16.8cm+**	**16.7cm+**	**17.1cm+**	**15cm+**	**19.5cm+**
Bottom/Hip Circumference	96.5-147cm	114cm	112cm	114.5cm	97cm	114.6cm

+ outside of NFPA 1977 size range

Conclusions

The analysis demonstrated usability of mobile 3D body scanning as a method for body measurement collection of female firefighters. There is also an opportunity for improvement in sizing for wildland shirt and pants as the current standard sizing requirements do not accurately capture the range of female firefighters. There is a similar opportunity for improvements in sizing guidance for structural turnout gear specified for women, as a significant portion of the study's participants had fallen outside the size range requirements.

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Development of an obstacle course to evaluate the ergonomics of military prototypes

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Keywords
LEAP, ergonomics, comfort, prototype assessment, military obstacle course, ergonomics test protocol

Introduction
An obstacle course for military prototypes' assessment using own military training facilities has been developed to evaluate its ergonomics through the performance of typical military movements. This evaluation was based on the Loads Effects Assessment Program (LEAP) developed by the U.S. Marines (1). The LEAP tool consists of a series of obstacles and mission-relevant activities/movements to resemble challenges that soldiers face in combat situations, on the theatre of operations. The soldiers participating in the LEAP assessment go through stairs, ladders, tunnels, windows, walls, and balance beams. They perform numerous mission-related tasks, including load transfers, simulated casualty drags, low crawls, high crawls, back crawls, and sprints. In this obstacle course many potential movements and activities of a regular military mission into a single tool are condensed. The soldier's performance, including subjective opinions, provide knowledge in terms of range of motion, comfort, flexibility, and mobility as well as the impact of the configuration worn.

Methods
Typically, the soldier equipment consists of many individual components and modules that must be seen and treated as a whole system. A soldier system is an integrated set of articles/components that soldiers wear, carry, consume or control to strengthen their individual capability and the capability of their fighting unit. This capability can be affected when a new element is added and can be assessed throughout a simulated course. The LEAP program consists of a 10-station obstacle course, transportable, comprising also an area for answering questionnaires once the course is completed. The several segments of the course are depicted in Figure 1a.

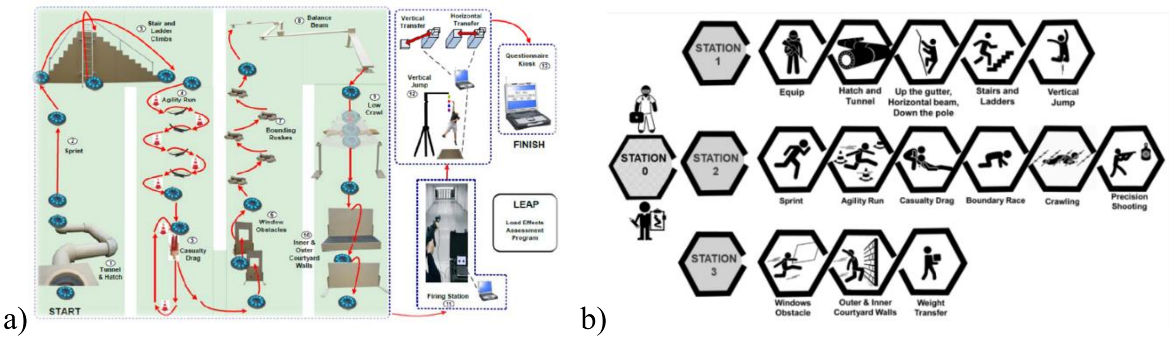

Figure 1. a) LEAP obstacle course: 10 stations plus firing range, vertical jump and questionnaire kiosk stations(1); b) LEAP - based obstacle course: 3 stations, 14 movements total. Station 0 for data collection, medical support and starting point.

Based on the LEAP course, CITEVE and the Portuguese Army developed an obstacle course (Figure 1b), which allowed for prototype ergonomics assessment. This course consists of 3 main stations, where a series of movements are performed by the user. It includes: 1) Equip, 2) Tunnel and hatch, 3) Up the gutter, horizontal beam, down the pole, 4) Stairs and ladders, 5) Vertical jump, 6) Sprint, 7) Agility run, 8) Casualty drag, 9) Boundary race, 10) Crawling, 11) Precision shooting, 12) Windows, 13) Outer and inner walls, 14) Weight transfer. Station 0 corresponds to the location where the group of military users will start and end the exercises of each station, as well as where questionnaires and physiological data will be collected (user feedback and physiological measurements), and the health support station will be present throughout the obstacle course. Two types of questionnaires are to be answered, one upon completion of each station and another, a global questionnaire, answered upon completion of the total course. After completing each station, the military users are to be asked about the difficulties when performing the movements and asked to suggest, according to their experience, improvements on the matter. Physiological measurements are made, more specifically, heartbeat and body temperature. Additionally, station completion duration is recorded, and the military participants are asked at each station to indicate the level of perceived effort according to Borg Scale of Perceived Effort. Two different sets of prototypes were evaluated, one regarding personal ballistic protection vests, and the other regarding camouflage ghillies. All users were asked in the warm-up time questions such as age, weight and experience in using these types of equipment. Weather conditions were also registered.

Results and discussion

Using the LEAP - based protocol, two types of soldier equipment were tested, one concerning ballistic vests(2) and the other regarding ghillie suits(3). Weight was registered for each prototype, being V1 lighter than V2 and G1 lighter than G2. A reference combat uniform was worn by all the military participants underneath each prototype. During the realisation of the test protocol, each station completion time was registered for each prototype in use and the average time calculated (Table 1).

Table 1. Station duration average times for the prototypes and reference.

	Duration time (min)					
Course	**Reference Vest**	**Prototype**		**Reference Combat Uniform**	**Prototype**	
		V1	**V2**		**G1**	**G2**
Station 1	04:22	03:40	03:56	05:23	06:09	06:08
Station 2	01:57	01:59	02:02	02:03	02:14	02:33
Station 3	02:23	02:13	02:23	02:24	02:39	02:48

Comparing the Reference against the respective prototypes, it can be concluded that parameters such as weight and volume, among others analysed, can have an impact on the station duration completion. For example, since prototypes V1 and V2 are lighter than the Reference, the completion times are similar or smaller, with the exception on station 2. This could be attributed to movement 11) since shooting ability of the test users varied. On the other hand, when comparing results for G1 and G2, average time is lesser for G1 than G2 since it carries a lot of lesser weight and volume (G2 required extra equipment such as batteries). The exception is noticed in station one, where times were significantly higher than the Reference due to some of the test users during movement 3) revealed fear of heights to some extent. Naturally, G1 and G2 showed higher durations in all stations due to constituting extra layers in comparison to the reference combat uniform. Other parameters were also evaluated, according to each user's perception at the completion of the course using the questionnaires, namely, flexibility, agility, velocity, mobility, and general fatigue aspects.

Conclusions

The protocol developed by CITEVE and the PT Army revealed to be an effective and promising tool for prototype impact assessment on the ergonomics and freedom of movements of the military participants. In both sets of prototypes, the parameter weight could be related to the duration to complete the 3 stations. Comparing to the References used, in each assessment, inferences could be made in relation to the impact of each type of equipment concerning ergonomics and freedom of movements. Further studying, though, must be performed with larger sample groups to effectively standardize the test course aiming the future use for military equipment as well as all personal protective equipment.

Acknowledgement

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Procedures for use of personal protective clothing, its ergonomics

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Keywords
fire protection, PPC (Personal Protective Clothing), normative requirements, thermal properties, ergonomics.

Introduction
Human performance is best at normal body temperature (1) ranging usually between 36.5-37.5 °C. A person's body temperature varies depending on the intensity of work to be done, psychological stress and personal metabolic rate. To maintain this normal temperature level, it is necessary to achieve a balance between the work environment, clothing insulation and activity (2, 3). The working environment of firefighters and rescuers is complex since it is different both from the temperature effects at the workplace and on the way to it and from the risks of work. Therefore, when planning PPC, it is necessary to pay attention to all layers of clothing, their assembly, heat protection and water vapor permeability.

The R_{ct} value (m^2K/W) determines the thermal resistance of the material. It is measured with a sweating guarded hotplate (SGHP). The higher the R_{ct} value, the better the insulation properties. For example, to maintain body temperature and prevent frostbite, materials with higher R_{ct} values are needed at ambient temperatures around 10°C than at 20°C. R_{ct} value can be converted to clo value: 1 clo = R_{ct}/0.155. The clo value determines the thermal performance of materials and/or clothing. It is stated in the literature that it is basically possible to sum the clo values of different layers to get the total clo value of the clothing system (4). Thermal insulation can be measured both on a single material, layers of materials and on a finished garment taking into account ventilation in the garment and, using moving thermo manikins, the effect of the wearer's movements on the insulation can be considered.

The R_{et} (evaporative resistance) value determines the material's resistance to water vapor. The lower the R_{et} value, the higher the vapour permeability. It can be concluded from the literature (5-7) that R_{et} value of 0-6 is very good, 6-13 good and 13-20 m^2Pa/W satisfactory and anything higher than 20 is unsatisfactory. It is not easy to make measurements, the certainty of their results depends on the properties of the textile material, the stability of the equipment and the repeatability of the measurement setup.

The aim of the study is to analyse the thermal comfort and well being in the firefighters stational uniform and first level garment (warm underwear).

Methods
Since the regulatory documents of the State Fire and Rescue Service of Latvia do not determine the composition of the materials, nor the achievable heat and water vapor resistance values, measurements were made for the first two PPC layers – a station uniform for cold weather consisting of warm underwear and a second layer (pants and shirt). The warm underwear is made of 100% Merino (single jersey, 148 g/m^2) and the daily shirt and pants set of 50% Co /50% Pes (weave 4/1 satin, 275 g/m^2). The measurements were made for each layer separately, the theoretical total insulation value was calculated and the layers were measured (both cloths at the same time). Measurements were made using the Sweating Guarded Hotplate Integrated System (iSGHP) produced by Thermetrics (USA) according to the ISO 11092 standard (8).

Results and discussion
The measurement results are summarized in Table 1. R_{ct} and R_{et} mean values of 3 samples are given, the standard deviation (SD) is given in square brackets. Although standard (8) does not require SD to be specified, due to measurement uncertainty and high variations, SD should be calculated for measurement reliability.

Figure 1 shows that the summation of the R_{ct} results does not give the same result as the measurement of the two-layer complex. Although the warm underwear material has a much higher heat resistance, the set of both materials does not even reach the value of 1 clo, it may be necessary to review the parameters of the materials. A clo value of 1 means that an average adult wearing two to three layers of clothing (such as a suit) can maintain thermal equilibrium in an environment at 21 °C (low activity level only). The thermal performance of insulation increases with clo value, meaning the higher the clo value, the better the insulation.

Table 1. Results of measurements.

Layers	R_{ct}, m^2 K W^{-1} [SD]	R_{et}, Pa m^2 W^{-1} [SD]
50%Co/50%Pes	0.012 [0.001]	0.913 [0.363]
100% Merino	0.051 [0.001]	5.659 [0.136]
∑ (theoretical)	0.062 [0.001]	6.571 [0.492]
Both layers measured	0.072 [0.004]	9.119 [0.212]

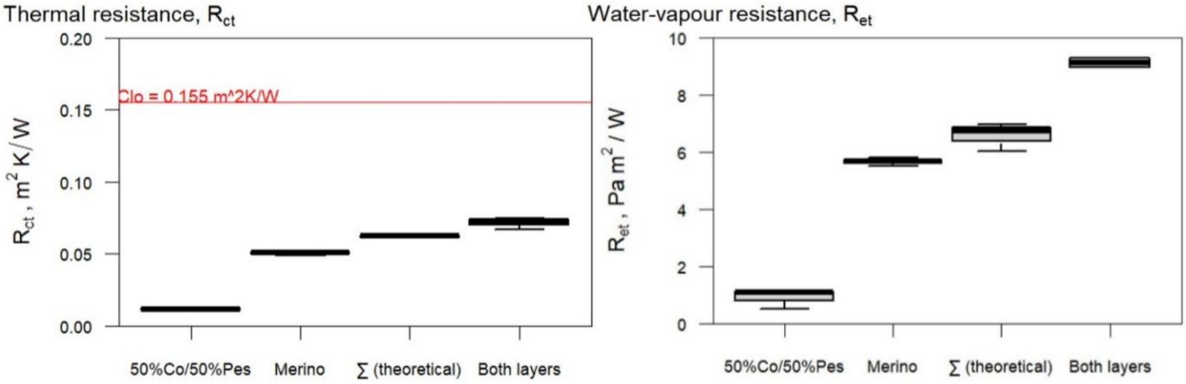

Figure 1. Results on measurements, SGHP, R_{ct}, R_{et} (9).

The R_{et} measurements shown in Figure 1 also allow us to conclude that the sum of two materials is not a measurement of the layering of the two materials (in this study, material tests are described, the materials are tested overlying without an air gap, which occurs during the wearing of clothing, which allows the summation to be performed without taking into account a theoretical air gap as per standard (4) and in the clothing air gap research (10)). The water vapor resistance measurement also shows an even greater difference from the theoretical calculation. In addition, the first of the 3 measurements turned out to be inadequately low: 1st sample 2.440, 2nd sample 8.969 and 3rd sample 9.269 m^2 W^{-1}. The measurement is not considered as an outlier; however, the amplitude of the measurements indicates that the small value is not correct – the measurement is even lower than the individual R_{et} value of one layer. If this were not a layered measurement in a series of measurements where the R_{et} values of the other two materials are already known, the layering values would be unreliable and additional measurements would be required.

Conclusions

Measurements of heat and water vapor resistance allow us to understand the ability of PPC layering to protect rescuers and ensure the ability to provide the necessary microclimate conditions. Although the existing methods allow for complex measurements, the standard's requirement to measure 3 samples may turn out to be too small, in addition, the SD value should also be indicated - to check the reliability of the data. More measurements are planned in the next stage of this study, including repeated testing and error analysis. Further studies also include measurements for ready-to-wear ensembles, according to ISO 9920 (4).

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Knowledge mapping of ergonomic issues in firefighter's protective clothing: a bibliometric review

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Keywords

firefighters protective clothing, knowledge mapping, performance analysis, content analysis

Introduction

In firefighting protective clothing (FFPC), ergonomics and physiological performance aspects are significant areas of concern, and researchers are utilizing various strategies and methods to improve the performance of FFPC. This study attempts to apply the science mapping tool to understand the ergonomics issues discussed in the firefighting protective clothing literature review and highlight the recent research trends and developments in the identified themes in firefighting protective clothing research over the past 32 years.

Methods

For the bibliometric analysis, Web of Science (WoS) was used to collect raw data from the bibliometric record of 801 Paper retrieved by keywords linked to firefighting protective apparel. Sports sciences provide the primary method for evaluating how well firefighters perform physiologically while wearing protective gear, hence WoS's Citation Topics Meso category - "Sport's Science," selected along with "Gait and Posture," and "Forestry," yielding 472 records; additional manual exclusion yielded 423 papers. The Science Mapping software tool SciMAT used for performance and content analysis. A decoupling process was applied to prevent the repetition of the authors and keywords.

Results and discussion

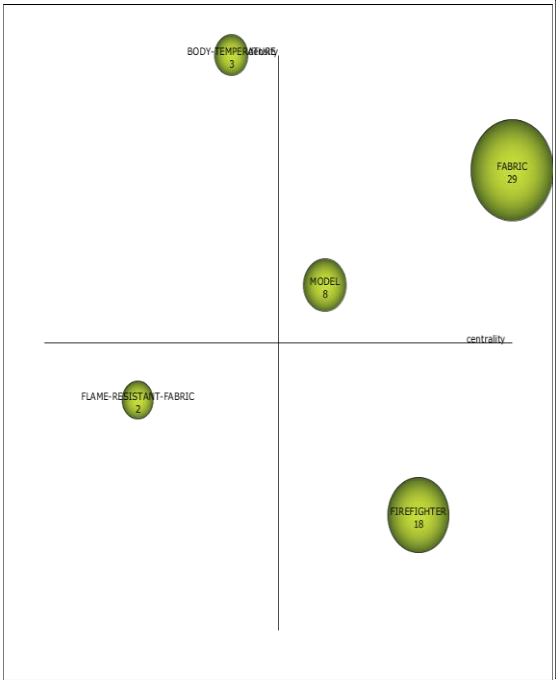
A Science Mapping software tool SciMAT software (1) was used for the performance analysis of different entities like documents, Authors, Affiliations References and Countries. As per (1) "Different visualization techniques are available, such as the strategic diagram, cluster network, evolution map, and overlapping map. The strategic diagram show the identified clusters of each period in two-dimensional space and categorize them according to their Callon's density and centrality measures." Research theme was identified by applying a clustering algorithm in SciMAT on the Co-word network analysis followed by visualization of thematic network and a strategic diagram for the identification of the major themes.

Table 1. Major clusters/themes for the last two periods.

Clusters information (2010-2015)				**Clusters information (2016-2022)**		
Sr	**Cluster Name**	**Centrality (Cen. range)**	**Density (Den. range)**	**Cluster Name**	**Centrality (Cen. range)**	**Density (Den. range)**
1	Air – Gap	18.32 (.75)	14.91 (0.75)	**Fabric**	27.45 (1.0)	9.79 (0.8)
2	Firefighter	33.88 (1.0)	05.5 (0.50)	Firefighter	21.69 (0.8)	3.13 (0.2)
3	Fabric	11.47 (0.5)	22.05 (1.00)	Model	9.69 (0.6)	9.08 (0.6)
4	Physiological Response	04.70 (0.5)	2.71 (0.25)	Body – Temp.	7.09 (0.4)	10.94 (1.0)

The related relationships of the subtheme or keyword are further provided by each cluster (Table 1) and its associated network diagram, as shown in Figures 1 and 2 for a cluster with the highest centrality for Fabric.

An evolutionary map shows the evolution of themes throughout six time periods, from 1990 to 2022. The content analysis also gives top-cited research papers of related themes in each cluster. To improve fabric performance in terms of TPP ratings & moisture management, researchers have experimented with fabric development using PCM, PCM, and Aerogel (2), Superabsorbent material (3). Similarly, extensive research conducted on the modification of the FFPC design (4), Modelling (5) & Air Gap (6) to improve fabric properties, thermal management of firefighting protective clothing.



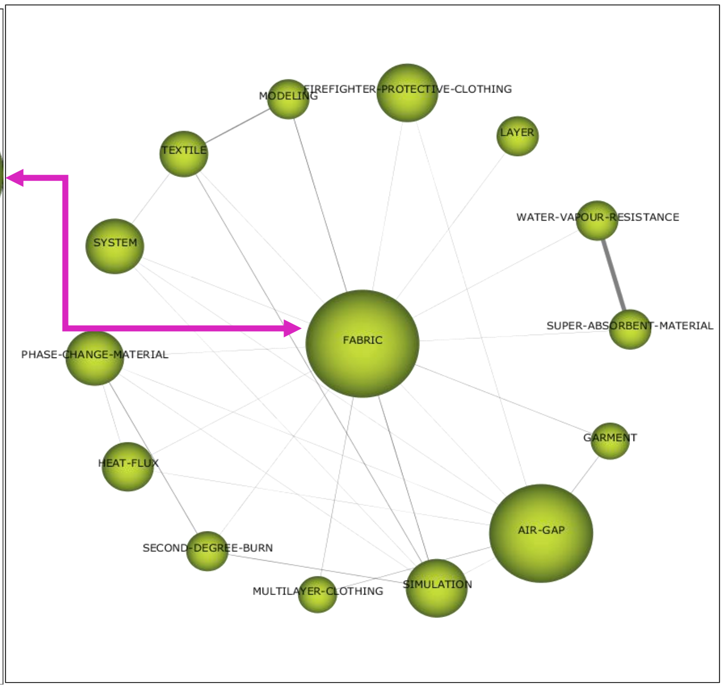


Figure 1. Strategic Diagram – 2016-2022.

Figure 2. Associate Network Diagram of System.

Conclusions

The content and performance analysis of bibliographic references resulted in the identification of the main themes and their linked network, which represented the most recent research trends and developments. For the design and development of enhanced Fire fighters' protective equipment, the product developers can do new product development by studying identified recent trends in design modification, fabric selection with alternative fibres, PCM and/or aerogel, with appropriate air gap, and different modelling techniques.

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Evaluation of firefighter clothing materials performance

Polycyclic aromatic hydrocarbons (pahs) simulation for standardized ppe contamination using a cone calorimeter

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Keywords
combustion, cone calorimeter, PAHs, firefighter, PPE

Introduction
Firefighters' occupational exposure leads to adverse long-term health issues such as cancer and cardiovascular disease (CVD). Fire departments, personal protective equipment (PPE) manufacturers, and national occupational protection organizations are becoming more aware of the dangers firefighters face in the line of duty. Long-term exposure to combustion products such as fine particles, volatile organic compounds (VOCs), heavy metals, and other contaminants existing in the fire scene, and contaminated PPE are the triggers to these diseases. To assess the efficacy and efficiency of smoke protection (resistance) and maintenance (decontamination) of firefighter's PPE, an appropriate hazard simulation is necessary. It's critical to simulate a representative level of contamination and apply that to PPE exposure for both research needs and decontamination standard development consistently. Both field and laboratory research have provided measures on the emission from material combustion. Large-scale field combustion intends to provide more realistic simulations, while bench-scale simulation often measures the accurate emission from individual material combustion. To apply this for industry and occupation standards, a contamination simulation in small-scale with representative emission resembling large-scale combustion is expected. The consistency of emission and similarity to the field contaminants are two critical criteria. This study targets 16 EPA PAHs as major hazardous compounds to measure these two criteria.

Methods
This study was conducted under well-ventilated conditions using a cone calorimeter according to ASTM E1354-17. Pine, Oak, polyvinyl chlorine (PVC), and polystyrene (PS) were selected to represent two common types of building material (wood and plastic) found in American houses. Materials were cut into 100 by 100 by 15 mm blocks before pre-condition. The nominal exhaust system flow rate from the combustion chamber was 0.024 m^3/s for all tests. Specimens were tested at irradiance levels of 25 kW/m^2 and 50 kW/m^2. A customized smoke sampling system was developed from a sampling port on the horizontal exhaust duct. After a dilution cylinder, one PAH sampling system and a cascade impactor (model 135-Mini-Moudi™ impactor, MSP, TSI Inc., USA) were applied to collect smoke particles. To collect both gas- and particle-phase PAH, a quartz filter (Hydrophilic quartz fiber filter, Merck Millipore Inc., USA) and a XAD-2 resin (ultra-clean resin, Restek Inc., USA) tube were used. Sample preparation for PAH quantification followed EPA 8270 recommendations. The sample was extracted with methylene chloride in the ultrasonic bath under cold water conditions. PAH concentrations in the extract were determined using gas chromatography and mass spectrometry (GC/MS). Individual species were identified by MS using the NIST database. A standard 16-PAH calibration mix (610 PAH calibration mixA, Restek) was used to quantify individual PAHs.

Results and discussion
Figure 1 shows the 16 PAH distribution among four materials combustion in this study. It can be seen that there is a large difference of PAH emission between wood-based materials and polymeric materials. While there is no significant difference between wood material PAH emission ($p>0.05$), higher heat flux increases the formation of PAH in each material, since temperature plays a critical role in material degradation and PAH formation. For wood-based material, gaseous PAH dominate the mass concentration (~95 %), the total PAH emission is similar to previous study from Blomqvist et al. (1) with the emission factor of 4 ug/g from wood board combustion under well-ventilated conditions. Another study got a higher PAH from Pine and painted pine combustion (2). The possible reasons are the difference of material, collection system, and the PAH analysis process including extraction and GCMS. More particulate PAHs formation occurs in polymeric material combustion (30-50 %). The PAH emission from plastic material shows a larger variance between different studies. Since the man-made plastic usually add additives to meet different performance needs, research results may show a different emission level, even with same type of material, such as polystyrene (2).

Compared to field investigation study, most PAHs are also detected from the material combustion, dominated by Naphthalene which is the gas-phase PAH. For PAH with lower volatility, 4-6 rings of PAHs contribute higher emission (3, 4). Field study usually detects a higher concentration of PAH due to the large-scale material combustion. However, considering the PAH distribution, there is a level of similarity that simulated emission resembles real fire condition.

Smoke collection from customized sampling lines have variance due to the particle loss during the transmission. By maintaining the temperature of the exhaust duct, controlling the collection flow rate, and regular maintenance, the experiment lowers the coefficient of variance (CV) to roughly 10 % in each combustion cycle. As shown in Table 1, Larger CV was found in PAH characterization. Polymeric material emission shows a better consistency than wood-based materials in both particle and PAH emission factor.

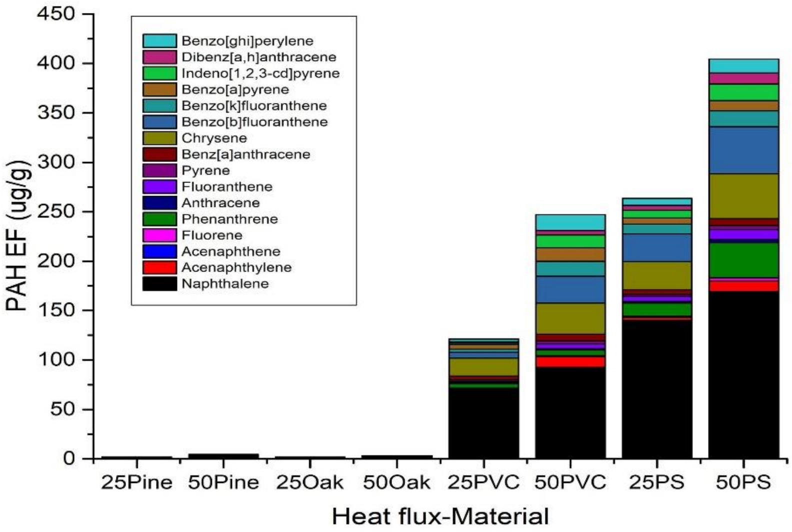

Figure 1. Distribution of individual PAHs emitted during the combustion of the materials under two-levels of irradiation heat.

Table 1. CV of smoke particle and PAH emission factor.

	25-Pine	50-Pine	25-Oak	50-Oak	25-PVC	50-PVC	25-PS	50-PS
Particle mass (g/kg)	13.34 %	6.98 %	7.69 %	5.98 %	3.22 %	1.16 %	9.11 %	10.82 %
Total PAH (ug/g)	21.53 %	64.20 %	25.66 %	52.76 %	5.03 %	23.82 %	5.64 %	17.58 %

Conclusions

Polymeric materials produce much more smoke particles and PAHs than wood-based materials. PAHs formation from wood-based materials are majorly light PAHs such as naphthalene and phenanthrene, while polymeric materials produce more heavy PAHs such as chrysene and benzo(a) pyrene (B(a)P). Consistency analysis shows the potential of using Cone calorimeter to characterize and produce specific smoke. Coefficient of variation is around 10 % for particle mass data, while the PAH determination involves multiple treatments which may increase the variabilities. The majority of the PAH types identified from fire grounds were detected in this study as well. This method shows promising potential to provide consistent and adjustable smoke emission for future research need.

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Risk assessment report (RAR) of polycyclic aromatic hydrocarbons (PAHs) in firefighters and instructors

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Keywords

contamination, dermal route, in vitro tests, virtually safe dose, risk assessments

Introduction

A **study** was **initiated** to carry out a **safety assessment for PAHs upon skin exposure due to a lack of scientific knowledge and/or evidence**. A healthy human skin forms an important barrier against chemicals, viruses, and UV rays. Skin exposure is mainly based on the donning and doffing of EN 469 X2 PPE during/after a fire, where the exterior of the PPE is contaminated and may be exposed to the unprotected skin. A toxicological qualification has been carried out for dermal exposure to PAHs. A virtual safety dose is used to assess the risks. Benzo[a]pyrene is the best studied and is often used as a marker for PAHs (Danish EPA, 2013). Given this, less than 2-fold variation between the profiles of carcinogenic PAH in these coal tars and in various foods, and the finding that the carcinogenic potencies of the coal tar mixtures could be up to 5 times that predicted by their Benzo[a]pyrene content, a conservative assessment would imply that the carcinogenic potency of total PAHs in foods would be 10 times higher than expected on the basis of the Benzo[a]pyrene content alone (SCF, 2002). For the calculation of the dermal safety limit the worst case dermal safety limit is based on the dermal safety limit in general population.

Methods

Firstly, the interface leakage using all PPE's was tested according to BS EN ISO 13982-1&2; Test method for determination of inward leakage of aerosols of fine particles into suits; and secondly the risks of dermal absorption was tested according to the OECD/OCDE 428 The Guideline for testing of Chemicals" – Skin Absorption: In Vitro Method.

Results and discussions

Inwards leakage tests

The interfaces of clothing do not completely prevent particles from penetrating. The highest values of **leakage** to the interior of the PPE were **observed at the lower legs**.

In Vitro tests

The contaminated textiles used for the In Vitro tests were samples taken from an EN 469 X2 jacket (2FG4F0PYS) that was used 5 times without cleaning during a fire simulation training. The level of contamination was tested according to AfPS GS:2014:01_Analysis Report 20.00307.01_Centexbel).

No permeation through the skin was measured after 24 hours of continuous contact between the contaminated textiles and the skin. **Very small amounts** of contamination were observed *on the skin* (see Table 1). The nature, size and physicochemical properties of PAHs are important; we observed a **negative correlation between molecular weight size and the amount of contamination on the skin**.

Table 1. Average results of outer layer, dry test, 24H contact , tape striping.

	(1) Average Mass recovery tape strips (µg/cm²)(2 cm²skin)	(2) Average Mass cumulative recovery receptor fluid (µg/cm²)(2 cm²skin)	(3) Average Mass recovery skin (µg/cm²) from 4 skin batches	(4) =(1)+(2)+(3) (4) **Average Dose absorbed (µg/cm²)**
Fluoranthene	$0.7825x10^{-3}$	$< 0.171x10^{-3}$	$1.055x10^{-3}$	$< 3.545x10^{-3}$
Phenanthrene	**$1.666x10^{-3}$**	**$< 0.855x10^{-3}$**	**$3.895x10^{-3}$**	**$< 6.416x10^{-3}$**
Pyrene	$0.545x10^{-3}$	$< 0.855x10^{-3}$	$1.911x10^{-3}$	$< 3.311x10^{-3}$
Benzo(a)anthracene	$0.585x10^{-3}$	$< 0.570x10^{-3}$	$1.713x10^{-3}$	$< 2.868x10^{-3}$
Benzo(a)pyrene	$0.216x10^{-3}$	$< 0.570x10^{-3}$	$0.535x10^{-3}$	$< 1.321x10^{-3}$

Risk Assessment

Based on **literature**, **information from firefighters** and **interface study** assessment of exposed skin surface was carried out. The skin areas that can be contaminated during firefighters 'activities are: neck (420 cm²), head (680 cm²), hands (600 cm²) and lower legs (1300 cm²). Together these regions represent a skin area of **3000 cm²** [Lund and Browder 1944], [EPA 2011].

Skin absorption was assessed using **In Vitro testing** according to the OECD/OCDE 428 The Guideline for testing of Chemicals" – Skin Absorption: In Vitro Method (Table 1). For the risk assessment the compound with highest exposure (in µg/cm²) was selected as worst case situation (see Table 1), i.e. Phenanthrene: 6.416×10^{-3} µg/cm². Assessment of the frequency was based on **information** of Firefighters and trainers.

Table 2. Results of risk assessment.

	Exposure time (in hour	VSD (in µg/working day)	Service time (in years)
BAUA (2013)	76880 (*)	14	40
Wobra	**1350 (**)**	**796**	**25**
ILLE-SRI	**3600 (**)**	**306**	**40**
BSPP	**1600 (**)**	**672**	**16**
SDIS30	**1240 (**)**	**867**	**40**

(*) Lifetime BAUA (2013) = 40 years, 48 weeks/year; 5 days/week; i.e. 9600 days

(**) service = exposed to smoke during fire or fire simulation

Hazard assessment was based on an include derivation/calculation of **safety limit by dermal route** taking into account conservative safety factor. Based on the **exposed skin surface of 0.3 m²** (part of hands, neck, head and lower legs), a dermal exposure of **19.25 µg/day** was obtained. A less-than-lifetime exposure is most realistic and **safety margins > 15.9 - 34.9 apply for instructors and fire(wo)men** (see Table 3).

Table 3. Safety margin after maximal exposure; based on a conservative approach. Skin exposure scenarios have been assessed from a conservative viewpoint (Wobra, BSPP, Nimes, ILLE-SRI).

Group Substances	Dermal exposure	Dermal safety limit	Safety margin
Polycyclic aromatic hydrocabons (PAHs)	**19.25 µg/working day** (6.416×10^{-3} µg/cm².24Hx3000 cm²) (Highest exposure value of **Phenanthrene** in **outer shell** intervention jacket)	**306 µg/working day** (exposure duration service **instructors** to PAHs)	***15.39***
		672 µg/working day (exposure duration service **fire(wo)men** to PAHs)	***34.9***

It has to be considered that if conditions would differ from the exposure scenarios in this risk assessment, one will have to adjust the Virtual Safe Dose (VSD) and the Safety margins. For example, if exposure is lower, there is a larger Safety margin. If the exposure is higher, one has to recalculate the Safety margins. I.e. if half of the skin is exposed to smoke, in other words 1.05 m² instead of 0.3 m², the skin exposure becomes: 6.416×10^{-3} µg/cm² x 10500 cm²/m² = 67.368 µg/working day instead of 19.25 µg/working day, resulting in a Safety margin of 4.54 for instructors, and a safety margin of 9.98 for firefighters.

Conclusion of the risk assessment

There is **no acute hazard or risk**, and on a **long term** basis, **the risk for systemic toxicity** and **carcinogenicity** is considered **very limited**. Provided that **PPE are correctly applied**, there is no concern for human health. It is advised to **wear all PPE**, the EN 469 level X2 clothing together with all other PPE; and all PPE needs to be compatible. Wear full ensemble **during all stages of fire, also overhaul activities**.

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Transitioning the fire service to pfas-free alternatives: trade-offs in exposure and performance

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Keywords
firefighter, PFAS, water/oil repellent, flammability, protection, trade-off, exposure

Introduction

Per- and polyfluoroalkyl substances, commonly referred to as PFAS, comprise a class of man-made toxic chemicals that have been used in thousands of consumer and industrial products and processes since their discovery in the mid-20th century. These chemicals have redefined the term "persistent" as they do not readily break down by natural processes and have been shown to bioaccumulate in plants, animals, and humans. They have been linked to multiple health conditions ranging from hypertension to cancer and are known to compromise the immune system. Dealing with these chemicals is a global issue, but there is heightened concern in the fire service due to the multiple potential routes of exposure that firefighters experience. PFAS compounds have been used on and within firefighter gear to impart oil and water repellency (1) as well as the polymeric forms being the main constituents of moisture barriers. They have also been used extensively as aqueous film-forming foams (AFFF) for combatting fuel fires, leading to dermal exposures and highly contaminated groundwater. In addition to these intentional sources of PFAS (those that serve a function or purpose for firefighting), firefighters are also faced with PFAS exposure from the fires that they are responding to as nearly every structure today contains multiple materials and products that are constructed with PFAS which will subsequently be released upon degradation in the fire. Recently, firefighters have led an intense effort demanding more accountability and transparency from organizations and manufacturers regarding the chemicals used in the production of their PPE, and they have demanded that these toxic chemicals be removed from their gear, since this is one source that can be controlled. Multiple research efforts have measured various volatile and non-volatile PFAS in both new and used gear (2,3). This presentation will detail the efforts of NC State University's recent research on PFAS in the fire service including assessments of both exposure and performance trade-offs between traditional gear and newer PFAS-free alternatives.

Methods

Assessments of performance trade-offs focused on repellency, flammability, and durability. Firefighter turnout materials were used in the following treatments: untreated (control), traditional PFAS treated (C6 sidechain fluoropolymer), and PFAS-free alternative treatments (silicones and hydrocarbon waxes). Materials were used in the new/received state directly from the fabric roll as well as after being subjected to cycles of multi-condition exposures including UV weathering, thermal exposure, and repeated laundering. Water and oil repellency were assessed through contact angle measurements and with a modified version of the ISO 6530 test for liquid repellency. Materials were exposed to water, diesel fuel, and petroleum-based hydraulic fluid. Following liquid exposures, materials were dried for 24 hours and then subjected to various thermal exposures including direct flame contact and radiant heat. Assessments of PFAS exposure trade-offs included evaluations of dermal absorption of select PFAS compounds as well as evaluations of leaching and thermal off-gassing of PFAS compounds from turnout ensemble materials (outer shell, moisture barrier, and thermal liner) in the new and aged states. The extent of dermal absorption of select perfluoroalkyl acids (PFAAs) was measured through in vitro flow through diffusion studies with porcine skin and a skin surrogate. Potential of PFAS to leach from treated fabrics was assessed over a 24-hour period while submerged in surrogate sweat at 37°C (elevated skin temperature). Thermal degradation and off-gassing of PFAS finishes were assessed at various temperatures via headspace gas chromatography.

Results and discussion

The commercial PFAS-free alternative finishes were able to provide sufficient water repellency to the fabrics but did not provide adequate repellency to diesel or hydraulic fluid. This finding was expected as the silicone and hydrocarbon wax finishes cannot replicate the low surface tension provided by the PFAS chemistries. The multi-condition aging process also showed that the performance of the PFAS-free alternative finishes degraded significantly compared to the traditional PFAS finish (Figure 1). A full 24 hours following chemical splash exposures, the vertical flame testing showed that sufficient flammable liquid was absorbed by the PFAS-free alternative fabrics to allow the materials to burn upon exposure to direct flame and sustain the flame until the flammable liquid was consumed. The traditional PFAS treated materials did not experience any flammability concerns in the new or aged states.

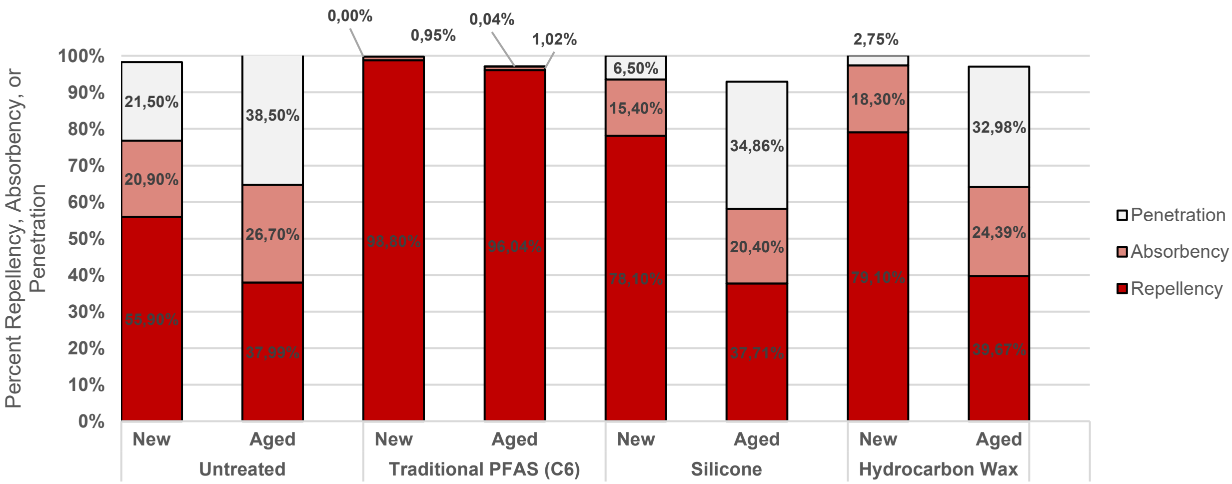

Figure 1. Repellency, Absorbency, and Penetration Indices for Materials Exposed to Petroleum-Based Hydraulic Fluid.

Evaluations of initial PFAS dermal absorption, leachability, and thermal off-gassing provided mixed results. Flow-through diffusion assessments of dermal absorption of PFOA, PFHxA, and PFBA showed that the ability to be absorbed into skin is dependent on multiple conditions including the pH and dosing vehicle. Thermal off-gassing assessments showed that sidechain fluoropolymers commonly used for repellent finishes degrade upon exposure to temperatures in excess of 150-200°C (easily attainable in a structure fire response) and release fluorotelomer alcohols (FTOH) and fluorotelomer methacrylates (FTMAC) that can further degrade to terminal PFAAs like PFOA and PFHxA. These compounds could then become primary respiratory hazards or settle in dust and lint and become secondary respiratory or ingestion hazards.

Conclusions

The field of personal protective equipment is all about trade-offs. In the transition of the fire service to PFAS-free alternative materials, it is important to understand the trade-offs that exist between the decrease in performance that the new PFAS-free materials provide and the potential exposure to hazardous PFAS compounds with traditional PFAS-treated materials. The decrease in oil repellency with silicone and hydrocarbon wax finishes is a concerning performance trade-off as firefighters can be regularly exposed to flammable fuels and oils on the job which may constitute a flammability hazard if wearing new PFAS-free turnout gear. While not a reason to stop transitioning away from PFAS-treated gear, this is a finding that fire departments must ensure that every firefighter is aware of and understands the limitations of the new gear. While the sidechain fluoropolymer finished fabrics have been shown to be able to release small molecular weight PFAS compounds and pose an exposure risk, further research is needed to understand how much the fireground (structure fire, wildland fire, vehicle fire) effluent contributes to the PFAS contamination on the gear and exposure to the firefighter.

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Decontamination of EN469 fire gear as an essential part of the firefighters preventive measures against cancer

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Keywords
decontamination, LCO_2, sustainability, clean room, fire gear

Introduction

Although, firefighters would appear to be well-equipped when it comes to self-protection, the matter of cleaning their Personal Protection Equipment (PPE) is a subject that needs further research. In the event of fire, many toxic substances are created, including polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and other substances that accumulate in the body (1–4).

It has been proven that the multilayer structure of the protective clothing of firefighters creates obstacles for effective disposal of toxic substances that contaminate this clothing (5, 6). This may result in a great risk of developing different illnesses among firefighters due to cyclical exposure to these substances (7–9). For this reason, it is found highly important to clean firefighters protective clothing properly (3, 10).

In firefighting terminology, cleaning and decontamination are often used as synonyms. However, it should be noted that there is a significant difference between cleaning, which is more general, and decontamination, which is a more specific concept (11). In the case of decontamination of firefighter clothing, it must be ensured that the undesirable substances are below the limit set by the relevant guidelines and standards. This helps ensure that the clothing is considered safe for health and proper use (12-13). Currently, firefighters clothing is not covered by decontamination standards, and the level of impurities contained are not measured. The clothes are only assessed visually.

A Report from a study run by the Finnish Institute of Occupational Health, the National Institute of Health and Welfare of Finland, and the Dutch Institute for Occupational Safety (IFV) showed the low effectiveness of most widely used cleaning method of firefighters clothing using water cleaning. This study shows that, despite the use of intensive water washing in specialist appliances, the washing efficiency of more than 40 per cent is not achieved. It should be noted that the washing temperature used for the study was 60°C, which is above the recommendations. However, this method of cleaning is widely considered sufficient. The study showed that the levels of PAHs and other harmful substances in the materials of firefighters' multi-layer clothing after water cleaning are exceeded. The average concentration of total PAHs in different samples of the multilayer material, in one of the tested jackets after water cleaning, was up to 550 ng/cm^2.

The authors of the study also stated that due to the fact that measurement results of harmful substances in the samples of the material tested after washing exceeded the permissible limits, other methods of removing contaminants from firefighter clothing should also be considered, such as ozonation, treatment with liquid carbon dioxide or a combination of both of these methods.

To prove the efficiency of the liquid CO_2 cleaning method, a test has been carried out on worn-out firefighter protective clothing. The samples were taken for testing from the clothing before and after decontamination with the LCO_2 method.

Methods

The tested clothing was used regularly for different kinds of fires and hazards for about 5 years This garment was washed regularly (after each major contamination or at least every 2 months) using a water cleaning industrial unit and a drying machine at the local fire station. When it was handed over to the CENTEXBEL laboratory in Belgium, the clothing was considered basically worn out. The clothing and was not washed before sending it to CENTEXBEL for testing.

At first, the representative samples of the external layer, membrane and lining, were subjected to ultrasonic extraction in toluene and then analyzed for polycyclic aromatic hydrocarbons (PAHs) content. This made use of gas chromatography techniques with a mass-selective detector (GC-MSD). The research was carried out in accordance with the procedure AFPS GS 2014.

Subsequently, the tested firefighters' clothing was sent to DECONTEX Benelux in Tielt for industrial cleaning according to the DECONTEX TECHNOLOGY® and sent back to CENTEXBEL laboratory for further testing of materials for toxic substances.

Results and conclusions

The project presents differences in results of PPE contamination between water cleaning examined in the Finnish experiment and decontamination described in the tests carried out on a worn out contaminated firefighters' jacket.

The term 'cleaning' refers to the removal of contaminants that are visible to the naked eye. The term 'decontamination' covers the effective removal from protective clothing of substances harmful to the user, which are not visible to the naked eye. Decontamination is a much narrower concept that requires compliance with a number of requirements.

Contact with fire residues in the contaminated clothing leads to the deposition of harmful substances in the firefighters' body through long and repeated exposure through the skin and breath, especially in the case of polycyclic aromatic hydrocarbons. Therefore, exposure to harmful substances should be avoided.

As shown in the project, liquid CO_2 cleaning method enabled to decrease the amount of hazardous substances in the structures of the PPE material from a level exceeding the limit by GS Mark to a level below the reporting limits of the laboratory devices.

The sum of PAHs in the outer layer decreased from 17.3 mg/kg to under 0.600 mg/kg.

The sum of PAHs in the membrane decreased from 29.5 mg/kg to under 0.600 mg/kg.

The sum of PAHs in the lining decreased from 1.76 mg/kg to under 0.600 mg/kg.

Until there are effective and widely available decontamination technologies in place, other guidelines should be followed that can help reduce exposure to harmful substances. Protective clothing should be taken off during breaks to avoid unnecessary exposure to fire residues emitted from contaminated clothing. It is highly recommended that liquid CO_2 cleaning should be taken into consideration to decontaminate the clothing at least twice a year due to the planned check-up of the PPE. This will reduce the exposure of the firefighter to harmful toxins in the clothing. It is also highly advisable to use LCO_2 technology after incidents where contamination is likely. As shown above, cleaning PPE in liquid CO_2 enables the removal of the PAH contained in the structure of the materials to a level that is not reported by the laboratory devices.

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Aging of firefighter outer shell fabrics under accelerated conditions

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Keywords
fire-protective fabrics, accelerated aging, degradation, thermal aging, ultraviolet radiation, hydrothermal aging, residual strength

Introduction

Firefighters, workers in the oil and gas industry, electricians, and military personnel, for example, wear protective clothing made of fire-resistant fabrics constructed from high-performance fibers (1). For firefighters' protective clothing, the outer shell is generally a blend of different fibers such as para-aramid, meta-aramid, polybenzimidazole (PBI), and polybenzoxazole (PBO). These high-performance fibers are known for their exception resistance to heat and flame when new. However, the corresponding fabrics may be affected by long-term exposure to heat (2), ultraviolet (UV) radiation (3), abrasion (4), and moisture (5). This study aims to explore how firefighters' outer shell fabrics respond to thermal, UV, and hydrothermal accelerated aging. After exposure to various aging conditions, the residual mechanical performance of the fire-protective fabrics was evaluated. Eventual morphological and chemical changes were also identified.

Methods

This study involves three fire-protective fabrics used as outer shell in firefighters' protective clothing. They are composed of blends of Technora®, para-aramid, meta-aramid, PBI, and PBO fibers (Table 1). To prevent any unintentional damage, the fabrics were stored in the dark in controlled laboratory conditions after reception.

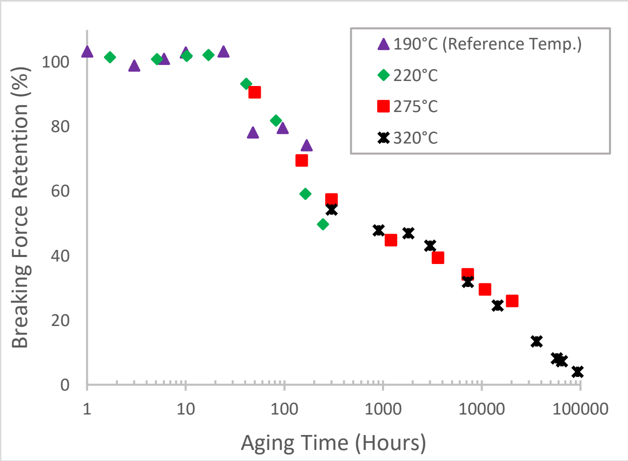
Fabric specimens were exposed to thermal, hydrothermal, and UV accelerated aging conditions selected considering the conditions encountered by firefighters while in service. Thermal aging involved subjecting the specimens to temperatures ranging between 90 and 320°C for up to 1200 hours in an air oven. For the UV aging, the specimens were exposed to UV irradiances between 0.35 to 1.35 W/m^2 at temperatures between 40°C and 80°C for up to 600 hours. Fabric specimens were subjected to hydrothermal aging by keeping them in hot water between 60 to 90°C for up to 1200 hours. For a comparison, the hydrothermal aging was also performed at room temperature. The fabrics' residual tensile strength after aging was assessed using the raveled strip method (ASTM D5035). Additionally, Scanning Electronic Microscopy (SEM) was used to analyze the eventual morphological changes in the fabrics. The chemical changes were analyzed using attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR).

Table 1. Characteristics of the fabrics used in this study.

Fabric Code	Fabric Composition	Fabric Structure	Mass (g/m^2)	Fabric Count (yarn/cm)		Warp yarn		
				Warp	Weft	Fiber content	Yarn type	Linear density (tex)
SA	60% Technora® & 40% PBO	Plain (Rip-stop)	247	22	19	Technora®/ PBO	Spun	57
SB	65% para-aramid & 35% meta-aramid	Broken twill	244	23	23	Para-aramid/meta-aramid	Spun	43
						Para-aramid	Filament	46
SC	65% para-aramid & 35% PBI	Twill weave	219	19	19	Para-aramid & PBI	Spun	58
						Para-aramid	Filament	71

Results and discussions

It was observed that the strength of all fabrics decreased for elevated aging temperatures and long exposure times, even when the accelerated aging was done at 190°C, which is equal to or below the continuous operating temperature of the high-performance fibers used to make these fabrics. The time-temperature superposition principle (TTSP) was applied to the residual tensile strength data to construct a master curve for each fabric (Figure 1). In the case of Fabric SA and SB, an Arrhenius plot could be constructed with the shift factors and was used to calculate the activation energy (Figure 2). In the case of Fabric SC, the breaking force was observed to initially increase before eventually decreasing. Fiber breaking was observed in aged specimens. It is thought to be the cause of the fabrics' decreased tensile strength. Chemical changes in aged specimens were also detected by ATR-FTIR analysis under the most extreme thermal aging conditions.



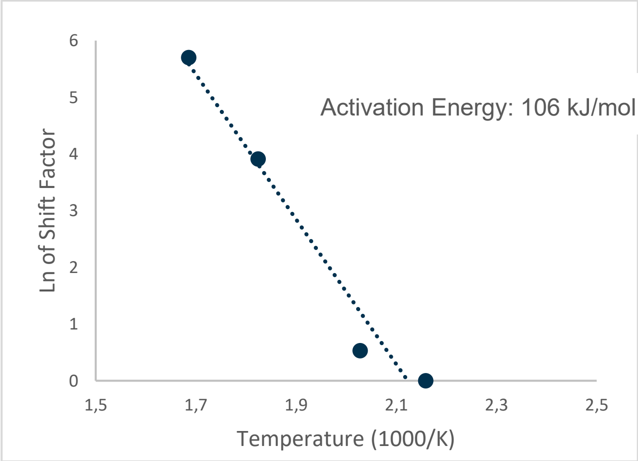


Figure 1. TTSP master curve at 190°C for the thermal aging of Fabric SB

Figure 2. Arrhenius plot for the thermal aging of Fabric SB

Findings from the hydrothermal aging indicate a severe loss in Fabric SC's tensile strength while the tensile strength of Fabric SA and SB was not affected significantly, even after 1200 hours of water immersion at 90°C. Further analysis revealed that the residual sulfur coming from the PBI fibers in Fabric SC was the cause of the premature hydrothermal aging of the fabric, which is potentially attributed to the hydrolysis of the para-aramid fibers in acid conditions (5). On the other hand, no evidence of change was detected on the fiber morphology and chemical structure of the hydrothermally aged specimens.

UV aging severely affected the tensile strength of Fabric SA and SB, while Fabric SC showed comparatively good resistance to UV conditions. However, evidence of changes in fiber morphology due to UV aging was observed for all the fabrics. No chemical changes were observed in the UV aged specimens.

Conclusions

This study explores how different aging conditions affect firefighters' outer shell fabrics. Depending on the type of aging and the fiber content in the fabrics, different behaviours were observed. In some instances, the decrease in tensile strength observed was very large. However, this decrease in strength of the aged fabrics was not always associated with morphological or chemical changes in the fibers. The findings of this work will support the development of predictive aging models and end-of-life sensors for fire-protective fabrics.

Acknowledgements

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Accelerated aging of moisture barriers used in firefighters' protective clothing

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Keywords

accelerated aging, apparent contact angle, firefighters' protective clothing, moisture barrier, tear force, water vapour transmission rate

Introduction

The protective clothing firefighters wear is what makes their job possible during firefighting activities (1). The moisture barrier is an essential layer in firefighters' protective clothing because it prevents liquid entry while allowing the body perspiration to exit. Researchers have shown that exposure to high temperatures, water, ultraviolet radiation, and laundering negatively impacts the performance of fire-protective clothing, which jeopardizes firefighters' safety (1, 2). Surprisingly, only limited research exists on the aging of moisture barriers (2-5). Therefore, this study aims at examining the effect of heat, moisture, and ultraviolet radiation on the tear force, water vapour transmission rate (WVTR), and apparent contact angle of three different moisture barriers used in firefighters' protective clothing.

Methods

Three moisture barriers commonly used in firefighters' protective clothing were selected for the study. Moisture Barrier 1 (MB1) is an expanded polytetrafluoroethylene (e-PTFE)/flame-resistant (FR) polyurethane (PU) membrane laminated on a Nomex® IIIA (93% Nomex®, 5% Kevlar®, 2% antistatic) woven fabric and a mass of 503 g/m^2. Moisture Barrier 2 (MB2) is a bi-component PU/e-PTFE membrane laminated on a Nomex® IIIA woven fabric and a mass of 580 g/m^2. Finally, Moisture Barrier 3 (MB3) is an e-PTFE/FR PU membrane laminated on an 85% Nomex®/15% Kevlar® nonwoven fabric and a mass of 536 g/m^2.

The accelerated thermal aging was carried out in an electric convection oven. Specimens were subjected to aging at 95, 190, 220, and 235/240°C (depending on the moisture barrier). Aging times ranged from 1 to 1056 h depending on the aging temperature. The accelerated hydrothermal aging was carried out by immersing specimens in water at 60, 80, 90, and 95°C for times between 24 and 600 h. The accelerated UV aging was performed under fluorescent lamps in the UVA range (315-400 nm). Specimens were exposed to a given combination of temperature (40, 50, 70, and 80°C) and irradiance (0.35, 0.68, 1.00, and 1.35 W/m^2 at 340 nm) for times ranging from 7 to 600 h. These conditions were selected to accelerate the aging and yield results within a reasonable time frame while being within what firefighters may face in service.

The residual tear force of the fabrics was measured by the trapezoidal procedure following the ASTM D5587-15; however, due to limitations in fabric availability and since previous research showed no effect on the results (6), a slightly smaller specimen size (55 x 110 mm) was used. The WVTR of the moisture barriers before and after aging was measured according to ASTM E96 procedure B (upright cup with water). The apparent contact angle of unaged and aged specimens was analyzed by a drop shape analysis (DSA) device. Scanning electron microscopy was used to evidence any potential changes in the membrane and fabric surface due to aging. One-way analyses of variance were carried out to analyze the influence of the aging time and aging condition on the mean tear force, WVTR, and apparent contact angle.

Results and discussion

Fout! Verwijzingsbron niet gevonden. shows the results of tear force retention for MB1 after thermal, hydrothermal, and UV aging. It also includes the water vapor transmission rates for MB1 after aging under the different conditions. For thermal aging (Figure 1.a), the small initial increase in the tear force at the highest aging temperatures may be attributed to the degradation of the PU adhesive and the associated increased yarn mobility. It is followed by a decrease of up to 30% in the tear force, possibly due to the degradation of the Nomex® IIIA substrate fabric, for which a retention force of 70% was reported after 42h at 235°C (7). The hydrothermal aging of MB1 leads to a slight decrease in tear force with an increase in aging time and temperature (Figure 1.b). After 600h of hydrothermal aging at 95°C, MB1 experienced a loss in tear force retention of 20%. Figure 1.c shows a sharp decrease in the tear force with aging time after UV aging. After about 150h of UV aging, the strength decrease rate slows down; the tear force eventually plateaus at less than 20% of residual tear force. This behaviour may be associated with the high sensitivity of aramid fibres to UV aging (3). There does not appear to be a strong effect of the aging temperature and irradiance on the mean tear force retention.

Higher temperatures and longer exposure times led to an increase in WVTR values after thermal aging (Fig. 1.d). This is attributed to the formation of cracks and the enlargement of the pores in the e-PTFE membrane. Partial closure of pores was also observed in some areas. UV aging also decreased the WVTR of MB1. On the other hand, there were not statistically significant differences for the WVTR after hydrothermal aging.

Degradation of the moisture barriers as a result of aging and the associated loss in performance were also observed in MB2 and MB3. Differences in behavior were found compared to MB1, which was attributed to the presence of the added PU layer for MB2 and the difference in the fabric substrate for MB3.

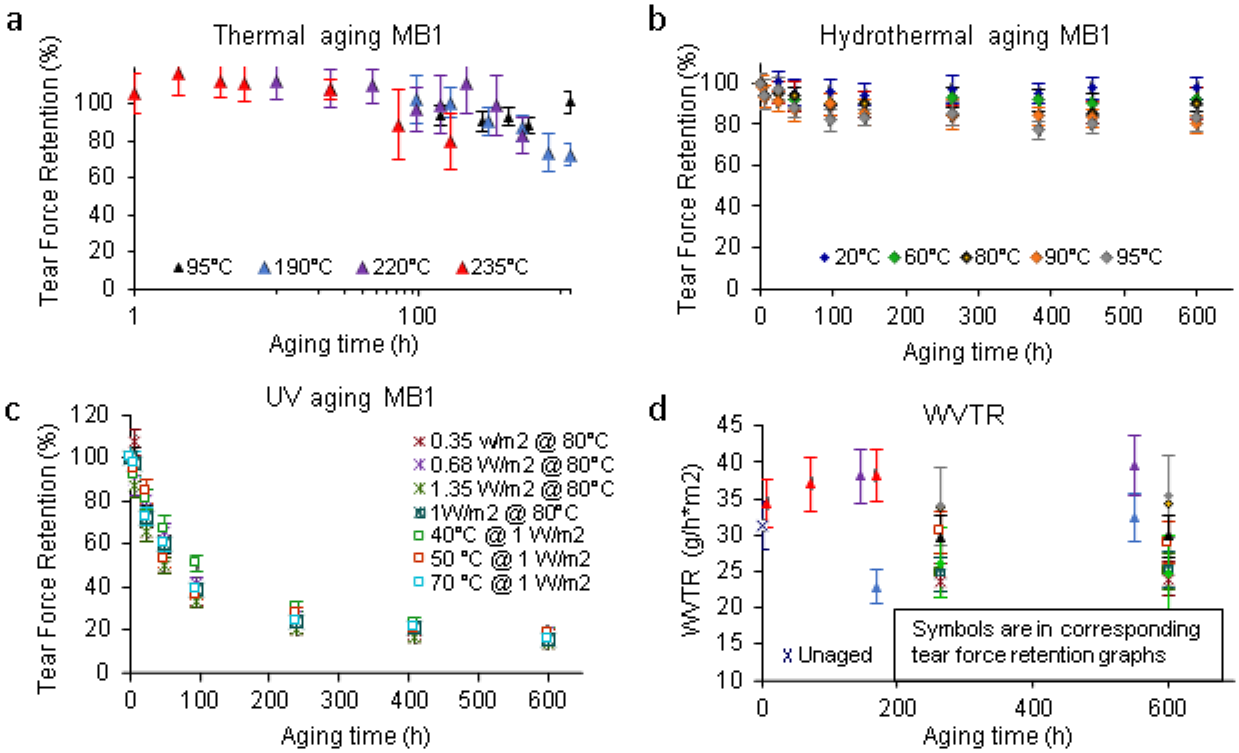

Figure 2. Tear force retention of MB1 as a function of aging time for (a) thermal aging, (b) hydrothermal aging, and (c) UV aging; (d) WVTR as a function of aging time for thermal, hydrothermal, and UV aging.

Conclusions

The results obtained show that moisture barrier's performance is strongly affected by thermal, hydrothermal, and UV aging. UV aging even at an irradiance as low of 0.35 W/m^2 reduced the tear force of MB1 by more than 80% at the longest aging time. Depending on the aging conditions, the loss in strength over time was attributed to the sensitivity of the Nomex® IIIA fabric to UV and in a lesser extent to heat as well as the possible degradation of PU adhesive and/or coating due to hydrothermal aging. Different behaviors were observed for the different models of moisture barriers tested, which was attributed to differences in structure and fiber content of the fabric and the presence of an additional PU coating. These results demonstrate the importance of better characterizing and understanding the effect of aging on moisture barriers' performance.

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Effects of tannic acid on flame retardant properties of jute and cotton

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Keywords
jute, cotton, tannic acid, flame retardancy, sustainability

Introduction

Jute fibers have gain importance recently because of its biodegradable, eco-friendly character and low-cost. These fibers are widely used in technical textiles such as reinforcement in composite materials for automotive and transport industry, and as carpets, carpet backings, upholstery, sacks and also as decoration objects. Cotton is the most common natural fiber for clothing. Because of its cellulosic structures, these fibers burn easily. However, jute technical products and cotton when used in flame retardant workwear require flame retardant properties. Instead of conventional flame retardant chemicals, like phosphorus-nitrogen products, biobased chemicals are preferred to fulfil environmental concerns. Tannic acid (TA) is a biobased, sustainable and natural product that give antioxidant, antibacterial, etc. properties to materials and also has good thermal insulating performance. Its molecule has outer and inner galloyl units which decomposes at 230-400^{o}C and 400-750^{o}C, respectively (1-10). The aim of this study was to investigate effects of TA-metal ion complexes with sodium and silver on flame retardancy, and mechanical properties of jute and cotton.

Methods

Plain weave jute fabric (J) having 214.1 g/m^2 and basketweave cotton fabric (C) having 239 g/m^2 were used in this study. Chemicals in the study were tannic acid (Tekkim, Türkiye) together with NaOH (Merck, Germany) and $AgNO_3$ (Tekkim, Türkiye). Recipes applied are given in Table 1. Tannic acid recipes were applied by two times dipping and nipping at room temperature. Pick-up ratio was 102%.. After dip and nip, fabrics were dried at 85^{o}C. After tannic acid application, fabrics were rinsed in distilled water for 5 minutes (3).

Table 1. .Recipes of tannic acid applications.

Chemicals	200T/50N	25T/5N	5T/1N	5T/2S
Tannic Acid	200g/l	25g/l	5g/l	5g/l
NaOH	50g/l	5g/l	1g/l	
$AgNO_3$				2g/L(6)

Analyses and tests were applied to fabrics before and after rinsing. Add-on values were calculated by the equation: Add-on(%)=[(dipped weight – untreated weight) / untreated weight] x100) for cotton fabrics. Burning characteristics were measured by limiting oxygen index (LOI – ASTM D 2863) and by vertical burning test. Ignition time was 12 seconds in vertical burning test, afterflame time and burnt length were measured. Tensile strength values were measured according to ISO 13934-1 in warp direction. Tannic acid treatment alters the color of the treated samples, therefore, color was measured and given in K/S, CIE L*a*b* values of the samples were measured in Minolta CM-3600d (D65-10^{o} observer angle). FTIR and TGA measurements will be presented.

Results and discussion

In this study, jute and cotton fabrics were treated by tannic acid together with NaOH or silver nitrate, because metal ions and sodium hydroxide supports flame retardant character of tannic acid treatments (6, 8, 9). Limiting oxygen index results of the cotton and jute fabrics were given in Table 2.

Limiting oxygen index results indicated that tannic acid treatment enhanced flame retardance properties of jute and cotton fabrics. Before treatments fabrics was easily burning but after FR treatments LOI values were increased at various ratios. J25T/5N sample before rinsing could be classified as flame retardant. LOI values of J25T/5N fabric before and after rinsing were 38% and 21%higher than untreated fabric. Cotton fabrics had a high LOI as 27% with the concentrated recipe and were a little bit durable to rinsing decreasing to 22.8%. The LOI value of jute fabric in this concentration (J200T/50N) was 26.1% (7). In the vertical flame spread test, JT100/N25 showed the best vertical burning result (flaming time: 14s, burnt length: 27cm), hence other fabrics were completely burnt. The increase in the flame retardancy may be the result of interactions of tannic acid and sodium ions, catalyzing decarboxylation of tannic acid and dehydration of cellulose (8). Vertical burning test results were worse than before rinsing. Color measurement results of cotton in terms of K/S and CIE L*a*b* values were given in Table 3.

Table 2. Limiting Oxygen Index Values of Jute and Cotton

Samples	Limiting Oxygen Index (%)	Samples	Limiting Oxygen Index (%)
Untreated Jute	18.2	Untreated Co	19.8
J25T/5N	25.6	C25T/5N	20.6
J5T/1N	21.2	C200T/50N	27.0
J5T/2S	19.0	C25T/5N-R	19.8
Untreated Jute-R	19.0	C200T/50N-R	22.8
J25T/5N-R	22.0		
J5T/1N-R	20.6		
J5T/2S-R	19.0		

Table 3. .Color measurement results

Samples	K/S	L*	a*	b*	Maximum Absorption wavelength (nm)
Untreated Co	0.0586	94.227	-0.493	4.706	400
C25T/5N	7.7395	43.210	18.974	22.397	440
C200T/50N	16.0400	25.721	10.871	9.290	430
C25T/5N-R	2.9121	59.237	17.708	25.332	450
C200T/50N-R	7.0697	44.437	18.883	22.710	440

Higher concentrations of TA have change the color significantly. Lighter colors with different maximum absorption wavelength were obtained after rinsing. While the color of untreated cotton fabric was white, that of the fabrics brown-like before and cappuccino-like after rinsing. Tensile strength values increased after tannic acid treatments.

Conclusions

This study is conducted to obtain sustainable flame retardant jute and cotton fabrics for protective technical textile applications. Effects of tannic acid treatment with metal ions sodium and silver on jute fabrics were investigated. We can conclude that bio based flame retardant property can be obtained for the both fabrics by especially sodium-tannic acid complex at high concentrations. After rinsing, LOI values were decreased. These values are not sufficient to be used in protective textiles and clothing and can be enhanced by developing recipes.

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Smart protection and innovative solutions in firefighter protection

Adaptable thermal insulation for heat and flame protection on demand

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Keywords
firefighters' clothing, thermal protection, burn risk, air gap, adaptable thermal insulation

Introduction
Firefighters and workers exposed to heat and flames need a high level of thermal protection. Heat and flame protection is normally achieved by three layer clothing combinations: 1) protection, 2) moisture barrier, and 3) thermal insulation. The thermal insulation is normally selected high enough to protect in worst case conditions (emergency situations such as flash-over situations (1)). Accordingly the thermal comfort of such clothing system is usually low for all other applications (2).

Adaptable thermal insulation on demand would allow good protection during heat and flame exposure while reducing the thermo-physiological impact during routine activities.

Materials and Methods
A clothing combination intended for worker with accidental contact to heat (Nomex coverall, 220 g/m^2) was equipped with air inflatable structures to provide thermal insulation between 0.005 m^2·K/W for the Nomex fabric and 0.1 m^2·K/W for the Nomex fabric and the air-filled structure inflated to 1 cm (Rct measured according to ISO11092).

The coverall with and without the adaptable thermal insulation was tested using the evaluation method of ISO13506 (3,4) in combination with a radiant heat source (manufactured by Empa). The garment was tested at two different exposure intensities and durations: 1) 5 kW/m^2 and 10 kW/m^2 for 2 min and 4 min. The air-filled structure was laser welded based on 2 layers of Sympatex laminate (100% PES, 135 g/m^2)

The radiant heat source consists of 6 heating rods (Silicon carbide (SiC) electric heating elements) heated by electrical current. The exposure intensity was set by adapting the distance between manikin and source and using a reference heat flux gauge (Medtherm 64-15SB-20 / Schmidt-Boelter).

The air-filled structure was designed to cover the torso consisting of chest, abdomen and the back. As the exposure was from the front, only chest and abdomen were evaluated.

Results and Discussion
Figure 1 shows the results of garment states and exposure conditions: burn risk and transferred energy.

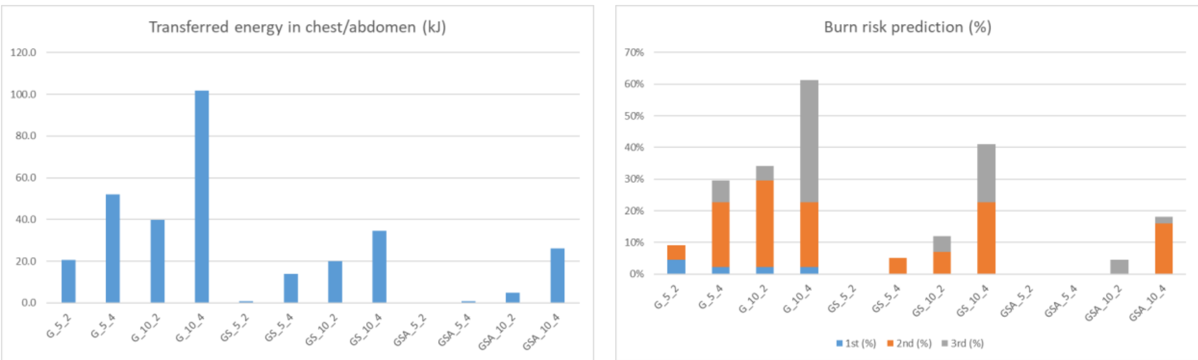

Figure 1. Transferred energy (left) and burn risk (right)
(G = garment; GS = garment + deflated structure; GSA = garment + inflated structure
1st number = exposure intensity in kW/m^2; 2nd number duration).

Conclusion and next steps
The results of this ongoing study show that it is possible to reduce the transferred energy and burn risk with an adaptable thermal insulation for the same exposure condition. The transferred energy and burn risk data increase with exposure intensity and decrease with the level of added protection.

At the highest exposure condition (10 kW/m^2) the outer material started to show color changes. At 10 kW/m^2 and 4 minutes of exposure the air-filled structure started to leak air which indicates potential damage to the laminate.

It is planned to repeat the tests with an optimized adaptable thermal insulation vest. This combination will then also be tested on the sweating Torso (ISO 18640) to assess the physiological impact. The measurements will take place in February and March 2023.

Outlook

The system could be equipped with sensors (temperature, heat flux) to change the adaptable thermal insulation automatically. In addition also an emergency inflation system using a small tank of pressurized air would be possible.

Acknowledgement

The authors like to acknowledge DuPont for providing the garments.

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The effect of wind speed, ventilation, air layer thickness, and air permeability on heat flux in two-layer systems

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Keywords
heat flux, air permeability, environment, test standards

Introduction
Sweating guarded hot plates are used to explore the insulation of fabrics in various test methods, such as ASTM F1868 (1) and ISO 11092(2). However, these test methods do not incorporate important factors that affect heat exchange during wear, such as ventilation, air permeability, and air layer thickness(3). The standards also don't include methodology for testing multilayer systems. Thermal manikin and human trials have been conducted on multilayer systems to explore the relationship between different environmental factors(4, 5). In this research, two-layer systems were tested on a hot plate to understand the fundamental relationship between fabric insulation, wind speed, and air layer thickness, utilizing fabrics of differing air permeabilities.

Methods
A sweating hot plate was used to explore the heat flux of a two layer fabric system, measurements were taken once the system was in steady state. The bottom layer was a cotton jersey knit fabric; the top layers were different fabrics of varying air permeability. "Spacers" were used to create air layers of 5, 10, and 25 mm; two different spacer designs were used, one to promote ventilation (with openings in the sides) and one to hinder ventilation (no openings in the sides). Wind was introduced perpendicular to the fabric surface at 0.25 and 0.5 m/s.

Results and discussion
Table 1 below outlines the relevant material parameters for the samples used. Note sample A is the material that was used as the base layer for all tests.

Table 1. Material parameters for samples. **indicates minimum value for test.

	Thickness (mm)	Air Permeability ($ft^3/min/ft^2$)	Density (g/m^3)
Fabric A	1.00	62.0	180
Fabric E	0.48	1220	135
Fabric F	0.87	0.56**	742

Figure 1 depicts the results of experiment. When the wind speed was increased, there was a general increase in heat flux values for the different fabric and spacer designs. However, for fabrics A and F, the spacer design that lowered heat loss yielded comparable values at the 0.25 m/s wind speed. This was not the case for both spacer designs at the 0.5 m/s wind speed. Samples A and F exhibited differences primarily at the 0 and 5 mm air layer thickness. This indicated a notable difference in the convective heat transfer that was able to occur when the amount of ventilation allowed was changed. Still, samples A and F demonstrated similar values at numerous combinations. This could indicate that there was not enough difference in air permeability between these samples to observe differences at all combinations. In the presence of any air layer (>0), Fabric E consistently demonstrated higher heat flux values than both materials, the air permeability of sample E was substantially higher than samples A and F.

Regardless of the material, there were some trends that appeared to be consistent. At the 0.25 m/s wind speed, there was a decrease in heat flux as the air layer increased from 0 to 5 mm. With the spacer without openings (reduced ventilation), the trend was for the heat flux value of the system to level off at the 10 mm air layer thickness. With the spacer with openings (higher ventilation), the trend was for the heat flux value to decrease from 0 to 5 mm and then increase slightly at 10 to 25 mm. The lowest heat flux value was generally observed at the 5/10 mm air layer thickness, The samples all appeared to begin converging towards a similar heat flux value at the 25 mm air layer thickness. This could be an indicator that the insulation provided by the top layer began to be much less important than the ventilation and air layer effects. However, since there was still some difference in the heat flux values, it can be concluded that there is still some insulation being provided by the top layer at an air layer thickness of 25 mm. At the 0.5 m/s wind speed, the spacer with no openings behaved similarly to the 0.25 m/s wind speed but began to level off at the 10 mm air layer thickness. However, the open design (higher ventilation) demonstrated a decrease at the 0 to 5 mm range but then a notable increase at 10 to 25 mm. Again, there appeared to be some convergence in heat flux values at the 25 mm air layer in the open spacer design, but the closed design did not demonstrate this trend. This exemplifies the effect of top layer sample, which was more notable at the higher wind speed.

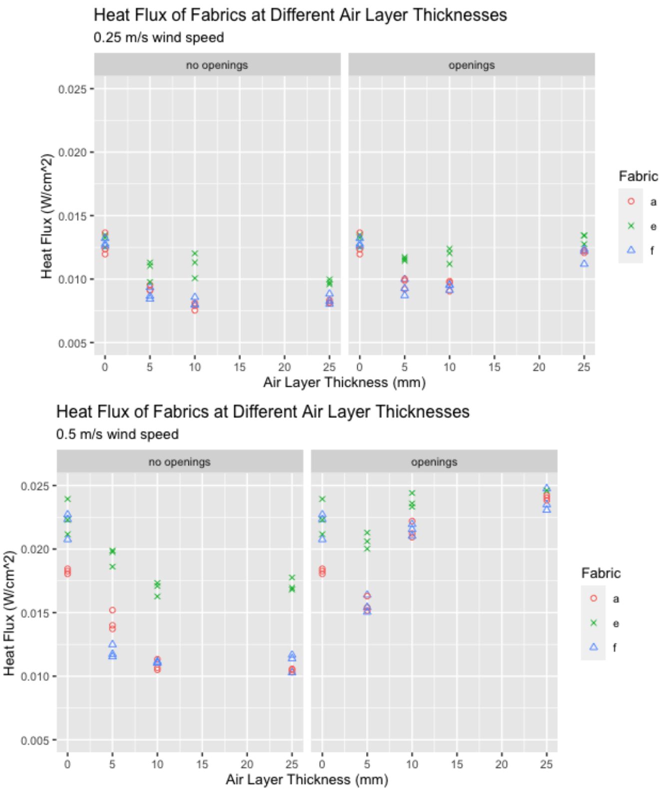

Figure 1. Heat flux of materials tested at 0.25 m/s wind speed (left) and 0.5 m/s wind speed (right), openings represents spacer design for increased ventialtion than no openings spacer design.

Conclusions

From the experiment, it can be concluded that differences in air layer thickness, wind speed, and ventilation can be successfully simulated on a hot plate. Similar trends were observed for different levels of these variables regardless of the material. However, the absolute heat flux value of the system was highly affected by the material parameters of the top layer. A limitation of this study was that the wind speed was perpendicular to the fabric surface, in ASTM F1868 (1) and ISO11092 (2) the wind is parallel to the fabric surface and the data obtained here may be modified by that different geometry. But, as these results and previous studies show, any experimental setup that allows fabric ventilation by allowing air to penetrate the fabric and exit the microclimate at another location will show similar effects of wind speed, air permeability, and air layer size. The low cost and availability of the apparatus, coupled with the results from these trials, allow for materials to be screened and evaluated for various applications. Incorporating these effects will lead to more realistic estimates of fabric and (protective) clothing insulation in real life.

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Smart firefighters PPE: impact of phase change materials

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Keywords
Phase Change Materials, thermal protection, firefighters, smart PPE, smart protection, advanced materials

Introduction

Considering the level of heat and flame exposure firefighters encounter while performing their working activities, the use of personal protective equipment is of utmost importance to enhance their safety. Therefore, in the past years several studies were performed with the aim of increase firefighters' protection and, consequently, decrease firefighters' heat load and skin burn. (1) Recently the use of phase change materials has been studied, in the scope of thermal protective clothing, considering the capability of these advanced materials to absorb and release energy in the form of latent heat, when phase transition occurs. (2) As a wide spectrum of PCM for textile applications is available, their selection should be done in view of the final purpose and considering properties such as heat storage capacities and melting point. For example, PCM with melting points close to body temperature are commonly used to improve thermal comfort, meanwhile for firefighters' thermal protective clothing, as the main purpose is to improve heat protection, PCMs with higher melting points and heat storage capacities should be used. (3) This study comprises thermal performance evaluation of different PCM (different melting points and heat storage capacities) integrated in an ensemble to simulate a possible thermal protective clothing.

Methods

In this study three different encapsulated phase change materials were analysed, varying intrinsic properties such as melting point and heat storage capacities, Table 2. PCM 1 and PCM 2 possess similar heat storage capacities but different melting points and both are in the powder form. Regarding PCM 3, this material presents lower melting point and heat storage capacity, and it is encapsulated in the form of a granulate.

Table 2. Phase change materials properties and characteristics.

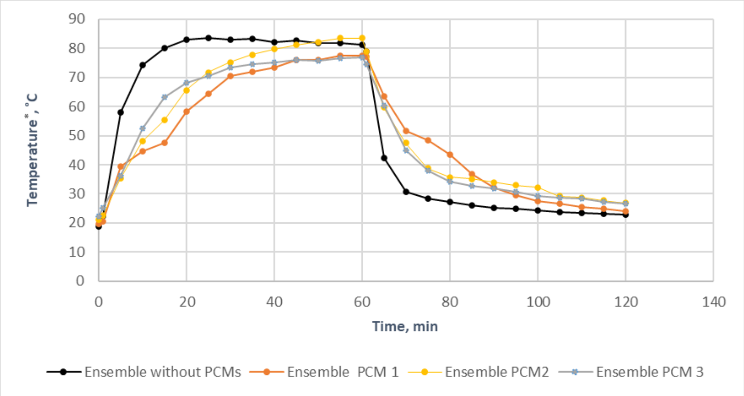
PCM	Melting /Congealing Area, ˚C	Heat Storage Capacity, kJ/kg	Form
PCM 1	77-85 / 85-77	105	Microencapsulated (powder)
PCM 2	49-53 / 52-48	100	Microencapsulated (powder)
PCM 3	38-43 / 43-37	55	Encapsulated (granulate)

To evaluate PCM thermal performance 6 grams of these materials were integrated in a membrane pouch, placed in a multilayer system composed by an outer shell fabric, 3D knit fabric, outer shell/cork matrix (to insert the pouch), and an outer shell layer. Afterwards, these ensembles were tested in an experimental set-up that was built for simulating convective and radiant heat exposure, Figure 3. This set-up consists of a 6x6 cm frame to support the sample, heated using a 1500 W heat-gun. A thermocouple was placed at the centre of the sample, on the opposite side of the exposure, to monitor the temperature over time. The samples are exposed to heat for 60 minutes and afterwards the heat source is turned off and the temperature decrease is also monitored for 60 minutes.

Figure 3. Experimental set-up for preliminary evaluation of PCM pouches: a) global view; b) heat source; c) sample frame; d) sample placed in the frame connected to a thermocouple; e) temperature acquisition device.

Results and discussion

In Figure 4, is possible to observe the increase of temperature over time when the PCM ensembles are exposed to the heat source. To set a term of comparison that allows the analysis of the improvement of thermal performance with the integration of the PCM, samples of the ensemble without PCM were also exposed to heat. The temperature was measured according to the method described previously.



*Temperature measured on the opposite side to heat exposure

Figure 4. Thermal performance evaluation of ensembles with and without PCM.

The figure above allows to observe the positive effect of the integration of PCM in the ensemble regarding thermal protection, since the increase of temperature was delayed in comparison to the results obtained in the ensemble without PCM. Furthermore, was also possible to conclude that within the PCM analysed, PCM 1 obtained better results in terms of thermal protection (major delay in the heating stage), as expected in the literature since this PCM presents higher melting points and higher storage capacities. However, the results presented show that the introduction of PCM delays the decrease of temperature during the cooling stage, while the samples without PCM cool instantly to 42,2 ˚C. The samples with different PCM have presented a similar cooling behaviour.

Conclusions

The results obtained allow to conclude that the integration of PCM contributes to increase the heat protection, delaying the increase of temperature on the heating stage, especially the PCM 1. Further work will approach the effect of PCM through the evaluation of heat transfer resistance (flame and radiation) according to EN 469:2020: Protective clothing for firefighters – Performance requirements for protective clothing for firefighters' activities.

Funding

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Development of graphene-based end-of-life sensors for fire-protective fabrics

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Keywords
fire-protective fabrics, end-of-life sensors, firefighter protective clothing, degradation, graphene.

Introduction

The protective clothing industry and workers at risk of exposure to heat and flame can rely on some high performance materials developed over the last fifty years to provide the protection needed while allowing some level of comfort. This includes a series of inherently thermal- and fire-resistant fibres such as para- and meta-aramids. However, if these materials exhibit exceptional performance when new, the various conditions they are exposed to during the lifetime of the clothing will reduce their performance over time (1). In addition, these large losses in performance may occur before any sign of damage is visible to the naked eye (2). Finally, the current increase in the laundering frequency of the protective clothing resulting from the discovery that smoke particles and combustion-generated carcinogenic chemicals can penetrate firefighters' protective clothing (3), will make obsolete the current retirement directives.

To tackle this critical issue, a graphene-based textile end-of-life sensor has been developed to allow monitoring the condition of the fire-protective clothing over its lifetime. The sensor will be stitched at a few strategic locations on the fire-protective clothing. The residual conductivity of the sensor will be measured using a simple multimeter as part of the regular assessment that firefighters and other workers at risk of heat and flame exposure are required to do of their protective equipment. Based on the values measured, they will be warned if their protective clothing has experienced a level of exposure to aging conditions that may have decreased its performance below the safe range and thus needs to be replaced.

Methods

The strategy used for the development of this end-of-life sensor relies on polymers that are sensitive to the same aging conditions as high performance fibres, i.e. heat, UV, and moisture (4). These polymers are combined with a graphene-based conductive track. Upon reaching a certain level of exposure to one of these aging agents sufficient to cause the fire-protective fabric to enter an unsafe range, the sacrificial polymer degrades, causing a disruption in the graphene conductive track and a change in its electrical conductivity. As illustrated on Fig 1, the UV-, heat- and moisture-sensitive components of the end-of-life sensor are secured on a fabric substrate that will be stitched as a patch at a few strategic locations on the firefighter protective clothing.

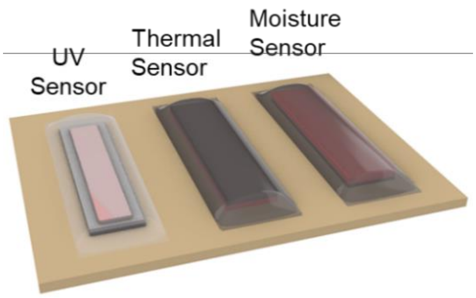

Figure 1. End-of-life sensor with the UV-, thermal- and moisture-sensitive components on the fabric substrate.

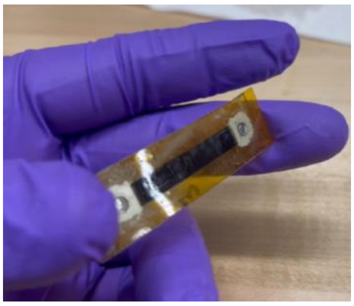

Figure 2. Picture of a thermal sensor prototype

Results and discussion

A picture of a thermal sensor prototype is shown in Figure 2. The sacrificial polymer selected for the thermal sensor is polyetherimide (PEI) as its activation energy upon thermal aging based on ultimate tensile strength data was shown to match that of fire-protective fabrics used as outer shell in firefighter protective clothing (5). In addition, the formation of cracks was observed at the surface of the PEI film as a result of aging, which would create a disruption of the graphene layer on the PEI film. This graphene layer was successfully prepared on PEI using laser engraving (4). The thermal sensor (Figure 2) also includes contacts so that the graphene residual electrical conductivity can be measured using a multimeter. The sensor is covered by an encapsulation layer; it has been shown to resist laundering, repeated bending, and abrasion (6).

In the case of the moisture-sensitive sensor component, polyimide was selected as the sacrificial polymer: its activation energy upon hydrothermal aging based on ultimate tensile strength data is similar to that of fire-protective fabrics used as outer shell in firefighter protective clothing (7). In addition, it becomes brittle upon water immersion in hot water. It also allows the formation of the graphene layer by laser engraving.

In terms of the UV-sensitive sensor component, a 2-pack polyurethane exposed to UV aging displayed the same trend in the variation of the tensile toughness retention as a function of aging time as fire-protective fabrics used as outer shell in firefighter protective clothing that were exposed to the same conditions (8). In addition, blisters were observed to form at the surface of the 2-pack polyurethane upon UV aging.

An appropriate fiber content for the end-of-life sensor fabric substrate has also been identified so that the fabric substrate does not interfere with the operation of the sensor (9). A blend of 93% meta-aramid, 5% para-aramid, and 2% carbon fibers (Nomex® IIIA) was shown to resist thermal and hydrothermal aging as well as laundering much better than the fabrics typically used as outer shell in firefighter protective clothing. On the other hand, it has a larger sensitivity of UV aging, which will be corrected with a UV-protective finish.

With all the different materials and manufacturing technologies now identified for the graphene-based end-of-life sensor for fire-protective fabrics, the next step is the scale-up to industry-scale production. This work is underway in partnership with the company Davey Textile Solutions, which has taken on to bringing the end-of-life sensor to the market (10). This company, which manufactures high visibility reflective trims, including for fire-protective clothing, has the production capacity to manufacture the graphene-based end-of-life sensors for the different steps of weaving, finishing, laser engraving, lamination, and product assembly.

Conclusions

Firefighters risk their lives every day to protect ours. Their protective clothing is critical to allow them performing their duties while remaining safe. Yet, the performance of their protective clothing degrades over time as it is exposed to high heat, UV light, moisture, laundering, etc., which raises serious concerns for their safety. A graphene-based end-of-life sensor for fire-protective fabrics has been developed to solve this issue. It is now moving towards commercialization with the company Davey Textile Solutions.

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This presentation was withdrawn

Sustainability in protective clothing and equipment

How does circular economy influence PPE?

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Keywords
Circular Economy, R-strategies, use and implementation for PPE, standardization

Abstract
The European circular economy action plan is one of the main building blocks of the European Green Deal, the agenda for sustainable growth. The Circular Economy has the transition of the value-added chain as a goal - away from a linear throwaway society to a circular model. A Circular Economy means that raw materials are used as long and as frequently as possible, and resources are used in a closed circle, without needing to use up new resources. This requires a rethinking of production and business models. Important properties and aspects for products in circular economy are durability, reliability, reusability, upgradeability, repairability, possibility of maintenance and refurbishment, presence of substances of concern, energy use or energy efficiency, resource use or resource efficiency, recycled content, possibility of remanufacturing and recycling, possibility of recovery of materials, environmental impacts and including carbon and environmental footprint. The European focus is on sectors that consume the most resources and where the potential for circularity is high. (e.g. electronics & ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water & nutrients). Some of these sectors are also relevant for personal protective equipment (PPE) products. PPE is designed to protect the wearer's body from injury or infection and includes very heterogeneous and diverse products such as clothing, gloves, foot and leg protection, head protection, respiratory protection, hearing protection, eye protection, protection against fall, protection against chemical/biological agents, smart PPE and others. How can sustainable aspects be integrated in the PPE products? What must be considered reaching the high protection and safety level and sustainability? The talk will give basic information of important R-strategies of the circular economy and examples how sustainability aspects can be implemented in different PPE products and where can be the limitations. PPE products must fulfill standardized requirements, and, in the future, sustainability requirements may be added in the PPE standards supporting more sustainable production and business models.

Development of an alternative flame retardant finish for textiles for fire protection applications and an adapted finishing process

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Keywords
anchor peptides, REACH regulation, fluorescence microscopy, flame retardants, peptide screening, textile finishing

Introduction

Flame retardants are widely used in consumer products, building materials and industrial environment to reduce the risk of fire. Fire protection of textiles plays an important role in our everyday lives and a flame retardant treatment is essential for ensuring the fire safety. Many of the flame retardant additives currently used are based on bromides, chlorides, antimony or phosphates. However, with an exception of phosphates, all these flame retardants are harmful to the environment and/or health. Therefore, the use of these flame retardants is already being restricted by EU directives (e.g. REACH regulation).

One of the aims of the research is to reduce the amount of flame retardants. In addition, the finish should be more durable against external influences. Anchor peptides are a highly diverse class of small amphipathic peptides (id.R. 30 to 100 amino acids) that bind selectively and with high binding strength to a broad portfolio of different materials and surfaces (e. g. textiles). Anchor peptides can be equipped with functional molecules, e.g. flame retardant additives, by chemical or enzymatic bioconjugation [1-8]. In this research, biohybrid flame retardants and an adapted finishing process are developed. Specifically, biobased adhesion promoters, the so-called anchor peptides, are used to finish textiles with flame retardant additives.

Methods

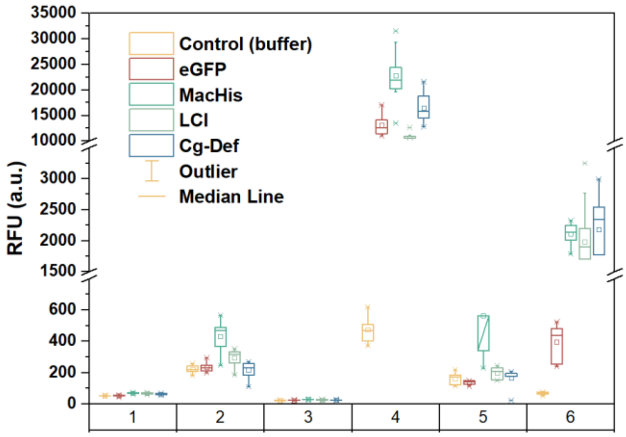
As a first step, possible textile applications are identified, and possible flame retardant chemicals and fabrics are defined. This is followed by a screening of the anchor peptide library of the partner BIOTEC (> 100 anchor peptide fused with green fluorescence protein (GFP) to identify anchor peptides with high binding strength, occupancy density and selectivity for different textiles (e.g., glass, aramid and natural fibres (e.g. linen). The functionalisation of the target textiles with anchor peptides is investigated in detail and detected using fluorescence microscopy, as the anchor peptide constructs are present as a fusion protein with a fluorescent reporter “GFP”. The biohybrid finishing of textiles with flame retardant additives can be achieved either by covalent functionalisation (bioconjugation) or by bifunctional peptides. In the case of bifunctional peptides approach, anchor peptides that are selectively binding to textile surface as well as to flame-retardant additives are screened by the partner BIOTEC. And then the bifunctional peptides are constructed by fusing two anchor peptides with different binding property (binding to textile or flame-retardant additives). The tailor-made bifunctional peptides enable flame retardant additives to be specifically applied in particle form to the target textiles. Parallel to the investigation of suitable anchor peptides, a suitable textile functionalisation process is being developed on a laboratory scale. First, a catalogue of requirements for the process is drawn up. Then various processes are compared with each other and evaluated with the help of a pairwise comparison. The process with the best result is designed and developed on a laboratory scale.

Results and discussion

Considering the importance and relevance of fire protection in high temperature industrial applications, blast furnace protection and flame retardant curtains are chosen as the application areas. So, different anchor peptides suited for glass-/aramid based fabrics and commercially available flame retardant additives are screened and selected. In Figure 1, the results of anchorage of different anchor peptides on different flame retardant additives are shown.

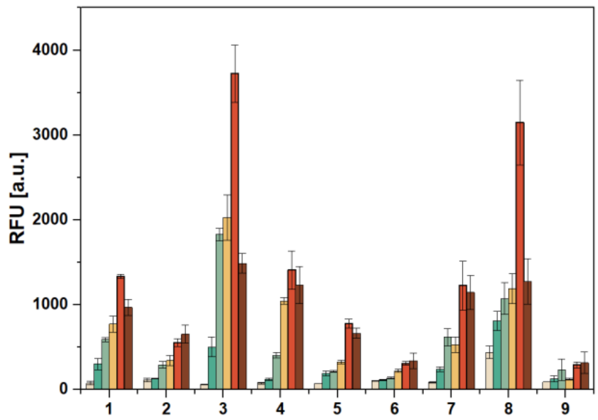
Flame retardants 4 and 6 achieve the best anchorage results with the anchor peptides MacHis, Cg-Def and LCI (flame retardant 6). Therefore, these chemicals are chosen for the finishing of the textiles.

The Figure 2 shows the results of anchorage of different anchor peptides on selected textiles. Three of the investigated textiles reached good results for the anchor peptides MBP1, MacHis and LCI. These textiles are KlevoGlass Itex 450-1 L, KlevoGlass 660 V4A-2 Karo and KlevoMid 290-3 L.



1 Addiflam S1MCP5050/500 (N19)
2 Addiflam Slurry DE 100/700
3 Blähgraphit ES100 C10
4 ATH Alfrimat 104
5 Addiflam Slurry APP F2 MF-500
6 Addiflam Pow MCA Eco

Figure 5. Anchor peptide screening for flame retardant additives.



1 KlevoGlass 320-3 RL
2 KlevoGlass 332-1 KK
3 KlevoGlass Itex 450-1 L
4 KlevoGlass 550 V4A-1 L
5 KlevoGlass Texo 640-1 L
6 KlevoGlass 660 V4A-2 Karo
7 KlevoGlass Texo 1260 V4A-1 P
8 KlevoMid 290-3 L
9 Optisyn 220

Figure 6. Anchor peptide screening for textiles.

Different finishing techniques were screened and in order to ensure an easy industrial scale-up, that too by using less quantities of the finishing liquor, foulard application was chosen. The foulard was designed and developed in ITA and various process parameters were optimised for its smooth functioning. The advantages of the foulard are the finishing of both sides of the textiles and that the application quantities can be set to 1g/m^2.

Conclusions

In this work, the anchor peptide library was screened for identifying the most suited textiles and flame retardant additives. Fluorescence microscopy was used as a tool to determine the level of anchorage on flame retardant additives as well as on textiles. Foulard based functional finishing process has been developed for KlevoGlass 660 V4A-2 Karo and flame retardants 4 and 6.

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Nomex® Comfort with EcoForce™

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Keywords

FR clothing, sustainability, multi-hazard, industrial

Background and aims

DuPont™ Nomex® Comfort with EcoForce™ technology fabric is an FR protective clothing delivering multi-hazard protection for workers in oil and gas and chemical manufacturing.

Its built-in flame-resistant protection helps the fabric maintain structural integrity and flexibility after exposure to flame, providing continued protection and mobility needed to escape. The fabric also delivers protection against liquid chemicals (according to EN 13034 (7)), arc flash, extreme heat, and static electricity.

The fabric's chemical-repellent finish is made from over 50 % bio-based materials and is not based on fluorine chemistry. Non-fluorine chemistry-based formulation was developed to achieve the Nomex® fabric hydrophobicity. Nomex® fabrics was grafted with % 100 free from alkyl fluoropolymers, where % 50 material is biobased. The repellent performance of the treated Nomex® was measured with the spray test in accordance with ISO 4920:2012 (1), the liquid chemical penetration/repellency/absorption indices measurement in accordance with ISO 6530:2005 (2) and EN 14325:2004 Clause 4 (3). The fabric mechanical and flame resistance properties including thermal manikin performance were also evaluated to verify the impact of the repellent technology.

DuPont™ Nomex® Comfort with EcoForce™ technology complies with the following norms: EN ISO 11612:2015 (4), EN & IEC 61482-2:2018 (5), EN 1149-5:2018 (6), EN 13034:2005+A1:2009 (7), NFPA 2112-2018 (8). Oeko Tex® Standard 100 (9).

Additionally, the fabric is highly durable and **has been certified after x100 cleaning cycles** without any re-impregnation of the chemical-repellent treatment.

Methodology

- **Certification after x100 cleaning cycles**: according to ISO 15797:2017 (10) industrial laundering requirements
- **Prediction of body burn injury**: ISO 13506-1:2017 (11)

Results and discussion

Table 1. Prediction of body burn injury.

Standard	Test Method	Norm	Unit	Value (*)
ISO 13506-1 :2017 (11)	Prediction of burn injury using an instrumented manikin 4 Second Exposure	2nd Degree Body Burn	**%**	**21.58**
		3rd Degree Body Burn	**%**	**0.2**

(*) *Nomex® Comfort with EcoForce Technology 225 gsm fabric weight - pretreated according to the ISO 6330 6N-F 5 Washing Cycles*

Table 2. Test results after x100 cleaning cycles under industrial laundering conditions.

Standard	Test Method	Norm	Unit	As Received	ISO 15797 100 Washing Cycles	Change (%)
EN ISO 11612 (4)	Heat resistance/shrinkage	ISO 17493:2016 5 minutes 180 °C	%	-% 1.2	-% 0.4	1%
	Limited Flame Spread Code A1	EN ISO 15025:2016 Method A	Code	A1	A1	
	Dimensional change after 5 washing cycles	EN ISO 5077:2008	%	-% 0.2	-% 0.2	0%
	Tensile Strength	EN ISO 13934-1:2013	N	1051	1085	3%
	Tear Strength	EN ISO 13937-2:2000	N	97	68	-30%
	Convective Heat Code B	ISO 9151:2016	s	5.1	5.2	2%
	Radiant Heat Code C	EN ISO 6942:2002 20 kW/m^2	s	15.1	14.2	-6%
	Contact Heat	ISO 12127-1:2015 T_c:250 °C	s	6.5	6.5	0%
EN 13034 (7)	Abrasion Resitance	EN 530:2010 - 9kPa- paper 00	cycle	>2000	1000 < X<1500	
	Tear Resistance	EN ISO 9073-4:1997	N	153.2	134.6	-12%
	Puncture Resistance	EN 863:1995	N	28.9	47.1	63%
	Resistance against penetration by liquids	EN ISO 6530:2005 H2S04 % 30 NaOH % 10 O-Xylen undiluted Butan-1-ol undiluted	%	R P H_2SO_4 %99.7 % 0 NaOH %99.4 % 0	R P H_2SO_4 %95.6 % 1.6 NaOH %96.1 % 0.7	R - %4.1 P % 1.6
EN 1149-5 (6)	Electrostatic dissipative behaviour	EN 1449-3:2004 Method 2	s	Half Decay Time T50 < 0.01 s Shielding Factor S > 0.81 s	Half Decay Time T50 < 0.01 s Shielding Factor S > 0.81 s	

Conclusion

DuPont™ Nomex® Comfort with EcoForce™ technology takes the sustainability of PPE to the next level thanks to its innovative chemical-repellent finish composition as well as its durability.

It passes the requirements of the following norms after 100 cleaning cycles: EN ISO 11612 (4), EN 1149-5 (6), EN 13034 (7). These characteristics increase the long-lasting wear life of the fabric decreasing the need for frequent replacements, which also helps to decrease waste.

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Recycling of post-consumer flame-resistantprotective clothing

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Keywords

fire-resistant garments, personal protective equipment (PPE), recycling, aramid fibres, shredding, blending.

Introduction

Aramids, a highly crystalline synthetic fibre, have found use in fire protective clothing, both in the civil and military sectors, due to their flame and heat resistance, excellent mechanical strength, absence of melting behavior, high durability, and good abrasion resistance compared to other fibres (1). This includes fire fighters, industrial workers, electrical workers, miners, and the armed forces. Protective clothing manufactured with flame-resistant (FR) fabrics are also used for protection again arc flash (2). However, aramids, which constitute about half of FR garments in Canada, are non-biodegradable, which leads to volume issues in landfills, and should not be incinerated due to the release of toxic gases and volatile compounds (3). The company General Recycled™ has taken on the mission to apply the 4 R's of recycling (recover/recycle/reuse/reduce) to FR work wear: they divert used FR garments from the landfill and use the recycled fibers to produce new FR garments (4). The recycling process of the FR garments is shown in Figure 1.

Figure 1. Recycling of used FR garments (Source: General Recycled™).

Methods

The recycling process of the used FR garments into new FR garments involves the following steps. At first, the used FR garments collected are cleaned and sorted based on fibre content. Then the metal zippers and other accessories are removed. The garments are further shredded into fibres using metal blade cutters. To compensate for the reduction in fibre length due to the mechanical recycling process, the shredded fibres are generally blended with virgin fibres. Yarns using the recycled fibres are spun using the traditional ring spinning process. These yarns are used to produce woven and knitted FR fabrics. The performance of the fabrics manufactured using yarns comprising recycled aramid fibres were assessed for conformance to different standard specifications such as CAN/CGSB 155.20-2017(5) for protective workwear against hydrocarbon flash fire and NFPA 70E (6) for arc-rated protective clothing.

Results and discussion

The flammability characteristics, thermal shrinkage, and arc rating of four fabrics with different structures, fibre contents, and recycled fibre percentages are provided in Table1. All fabrics passed the flame requirements as per CAN/CGSB 155.20-2017 (5): average damage length equal or lower than 100 mm, after flame equal or lower than 2 s, and no melt/no drip. Regarding thermal shrinkage, CAN/CGSB 155.20-2017 requires it to be equal or less than 10% in any direction: Fabrics A, B and C satisfy this requirement. In terms of arc flash, all fabrics have an arc rating of at least 8 cal/cm^2, which makes them suitable for category 2 hazards according to NFPA 70E (6). In fact, a study looking at predicting the arc rating of fire-resistant fabrics containing recycled aramid fibres showed that the recycled nature of the aramid fibres does not affect the arc rating of the fabrics (7).

These FR fabrics with up to 25% of recycled aramid fibres thus display excellent performance. In addition, they offer a large advantage in terms of reduced environmental footprint. A lifecycle assessment of garments made with yarns containing recycled aramid fibres was performed (8). It showed that a garment made of a polar fleece fabric with 15% of recycled meta-aramid fibres offers a 10% reduction in carbon footprint in comparison with a fabric with the same structure made of 100% virgin meta-aramid fibres. About 73% of the carbon footprint of this recycled aramid fibre garment corresponds to the raw materials stage. The 15% recycled aramid fibre yarns also lead to a 14% reduction in the impact of resource extraction. If large progress has been achieved so far, several technical challenges remain for the efficient and cost-effective recycling of aramid fibres from used garments and their use to produce new FR garments. In particular, it is critical to optimize the parameters of different processes involved when producing textile fabrics using recycled aramid fibres-stripping, shredding, fibre blending, yarn spinning, weaving, knitting, and dyeing - to achieve the best performance at the lowest cost.

Table 1. Flame resistance, thermal shrinkage and arc rating of recycled FR fabrics.

Fabric code	Fabric structure	Fibre content	Recycled content (Nomex IIIA, %)	Flame test for CAN/CGSB 155.20-2017			Thermal shrinkage (%) *	Arc rating NFPA 70E (cal/cm^2)
				After flame (s)*	Damaged length (mm)*	Melting/ dripping		
Fabric A	Knit jersey	Meta-aramid, Modacrylic, Cotton, Spandex, Antistatic	11	1.4/0.5	63/60	No	7.1/1.1	10 (EBT*)
Fabric B	Twill woven	Meta-aramid, Modacrylic, Nylon, Antistatic	15	0/0	96/89	No	9.0/3.8	8.6 (ATPV*)
Fabric C	Twill woven	Polyamideimide, Modacrylic, Antistatic	20	0/0	52/46	No	0.3/0.8	9.6 (ATPV*)
Fabric D	Twill woven	Meta-aramid, Modacrylic, Nylon, Antistatic	25	0/0	81/67	No	13.4/-	8.2 (EBT*)

*L/W= Length/Width; ATPV: Arc Thermal Performance Value; EBT: Energy to Break Open Threshold

Conclusion

In this project, we have developed more environmentally friendly aramid-based fire protective clothing and PPE through the recycling of used FR aramid protective clothing. The FR fabrics manufactured using the recycled fibres offer performance levels conform to the requirements as per specifications for protective clothing against flash fire and arc flash. In addition, the use of recycled aramid fibres to produce FR garments leads to significant reductions in carbon footprint and resource extraction impact, e.g. 10 and 14%, respectively for a 15% recycled fiber Nomex fabric. Even if some technical challenges remain, the work done here for the development of solutions towards the efficient recycling of aramid fibres pave the way for a wider adoption of recycling in the textile industry, with large benefits in terms of reduced demand for water and other resources.

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Sustainability in flame resistant protective clothing with viscose FR fibers – the day after tomorrow

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Keywords
flame resistant, personal protective clothing, sustainability, greenhouse gas emission reduction, CO_2 reduction

Introduction

Viscose FR fibers are sustainably produced inherently flame-resistant cellulosic fibers based on the renowned modal fibers production process. These fibers typically bring both protective qualities and enhanced comfort to various fabric blends contributing to fabric breathability that supports the body's natural thermal regulation. The fiber not only meets the definition of "inherently flame retardant and resistant fibers" as specified by the European Man-made Fibers Association (CIRFS), but also contributes to protecting the environment through efficient resource utilization. The fibers are produced through an integrated pulp-to- fiber process. The process predominantly uses surplus renewable energy from the pulp mill, making this fiber an environmental responsible choice as certified with the EU Ecolabel for textile products.

Methods

The methodology of LCA is based on international standards and considers material and energy flows from and to product systems, such as use of resources or emissions to air.

An LCA study looks at all flows entering and leaving the product system's boundary and calculates potential environmental impacts related to the representative functional unit, such as 1 kg fiber. Potential impacts are expressed in different categories such as Climate Change, Eutrophication, or Abiotic Resource Depletion. LCA is used to identify areas for environmental optimization of products not only during fiber manufacturing but also within the supply chain. By conducting cradle-to-gate LCA, potential environmental impacts are discovered for all upstream and core process activities until the fiber leaves the factory gate.

Results and discussion

As wood is the natural resource for wood-based cellulosic fibers, Lenzing mainly sources the wood from sustainably managed forests with FSC and PEFC certifications.

To protect ancient and endangered forests conservation solutions have to be implemented. Though the wood for fiber production comes from plantage forestry it is possible to respect wildlife and generate corridors to diversification exchange. These forests grow without the use of chemical fertilizers, and absorb large amounts of carbon dioxide. The timber used is primarily generated by thinning, which is unsuitable for high-grade products, for example in the furniture industry.

Viscose FR is a sustainably produced inherently flame-resistant cellulosic fiber based on the renowned modal fibers production process. These fibers typically bring both protective qualities and enhanced comfort to various fabric blends contributing to fabric breathability that supports the body's natural thermal regulation.

Viscose FR not only meets the definition of "inherently flame retardant and resistant fibers" as specified by the European Man-made Fibers Association (CIRFS), but also contributes to protecting the environment through efficient resource utilization.

The fibers are produced through an integrated pulp-to- fiber process. The process predominantly uses surplus renewable energy from the pulp mill, making this fiber an environmental responsible choice as certified with the EU Ecolabel for textile products. The EU Ecolabel is the European Union's official label for environmental excellence. EU Ecolabel products have a reduced environmental impact across multiple stages of the product lifecycle.

Dissolving wood pulp is the most important raw material used for Viscose FR fiber production. An vertically integrated plant produces the pulp required for fiber production on site, which offers ecological advantages, such as no need for transportation, and energy-intensive drying and packaging of pulp. Full utilization of wood is a key element because wood contains much more precious raw materials than just pulp. Half of the wood is transformed into pulp and other marketable biobased products, while any residue is used for bioenergy.

Viscose FR fibers can be blended with other high-performance fibers to produce unique fabric blend solutions for a variety of industrial applications. Such blends can be engineered to comply with all relevant global standards for protective wear, including EN ISO and NFPA standards.

There are also Viscose FR fibers available with Eco Color technology. They provide efficient ecological advantages, substituting the resource-intensive conventional dyeing process. This brings significant life cycle savings of water and energy from cradle to finished fabric. Also, these fibers offer long-lasting color retention – for even black, a very popular color – better than conventionally dyed fibers, and are less prone to fade even after repeated washing.

Carbon neutral Viscose FR is an offer for a next generation of sustainable fibers. It is a solution for the textile industry to address the urgent topic and challenge to reduce carbon emissions with the same excellent fiber performance. Derived from the renewable source, wood, both raw white and spun-dyed black Viscose FR fibers can be certified as compostable under industrial conditions.

Water is a precious resource and its increasing scarcity in many parts of the world is a threat. No artificial irrigation is necessary to grow the wood for Viscose FR, as they are part of the natural hydrological cycle and, as such, do not consume additional water.

Climate change is one of the most pressing challenges of our generation. In Austria, Viscose FR is produced in a fully integrated production process. In fact, Viscose FR fibers consume less energy and emit less CO2 than comparable products in the market. By using more than 83 percent of bioenergy, Viscose FR production generates around 80 percent less greenhouse gas emissions than generic modal.

The Higg Materials Sustainability Index_ (MSI) uses LCA to evaluate environmental impacts of materials in the textile industry. Figure 1 shows the environmental impact of different fibers according to HIGG MSI.

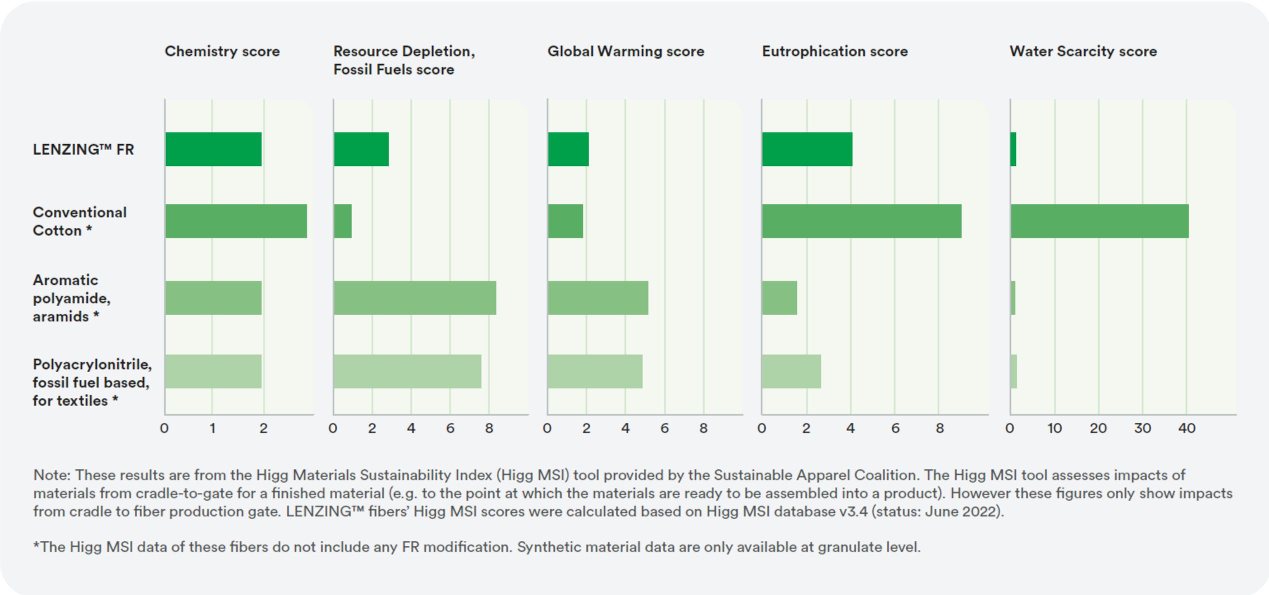

Figure 1. Environmental impact of different fibers according to HIGG MSI Database.

Conclusions

Life Cycle Assessment (LCA) is an important tool to assess environmental impact of textile materials. There are a number of options from fiber to garment, to improve sustainability of personal protective clothing without compromising safety and comfort of the user.

Medical protection - innovation in production and respiratory protection

Reservist project: Simulation of a rapidly deployment of an emergency hospital

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Keywords
emergency hospitals, reservist cells, digital platform, medical products

Introduction

The ongoing COVID-19 crisis has shown that several types of protective and medical equipment, services and even increased hospital capacity are crucial, including the ability to deploy them rapidly. Because of cost factors, these products, or at least critical components for them, are mainly produced outside the EU. To address the shortage during the COVID-19 crisis, many companies in Europe started with the production of protective equipment such as face masks (1,2).

However the situation is more or less normalized nowadays and EU companies are stopping with the manufacturing of these products due to the high production costs and they cannot compete with current market prices (3). To avoid that we face again a huge shortage of protective & medical equipment, governments are building up a large stocks, but as most of these products have an expiration date it happens that stock piles have to be destroyed because the products are expired. For example, the Belgium government had to destroy nearly €100 million of expired medical products (4) and also Germany incinerated 17,000,000 expired face masks (5). So it is clear that this is a huge waste of money and products.

Therefore, it is a real challenge to set up a concept that is focusing on creating extra capacity in spiking demand times instead of focusing on huge stock piles. This concept is developed in the Reservist project. So-called ‘Reservist cells’ are created, and these cells can in times of crises be activated within 48 hours to switch to the production of the necessary products when there is a spiking demand. The basis is the RESERVIST network, a wide group of actors linked through a digital platform. The Reservist Digital Platform (RDP) acts as a marketplace for medical products, emergency hospitals and services (6). This means that via the platform registered end-users can directly contact manufacturing companies to get products and manufacturing companies can use the platform to contact back up raw material suppliers. Further, the RDP has a situation awareness service to inform partners that they probably have to start up the production of the products because a certain disaster happened. This situation awareness service helps the partners to be better prepared for the requested production ramp-up.

In this contribution, a simulated situation is presented in which a well-equipped emergency hospital is ordered from the Reservist network and this hospital should be operational within a few days.

Methods

Information about the emergency and request for medical equipment and products is shared via the Reservist digital platform. All the involved cells, including the emergency hospital cells, immediately check their stocks, contact their suppliers and logistic partners to get the field hospital installed very quickly and provided with all the necessary medical equipment.

Results and discussion

Figure 1 shows how the digital platform looks like. The figure gives an idea on how the platform works. Reservist products can be found on this platform and can be requested by end users such as governments, hospitals, NGOs etc. in case there is a high need for medical products.

Fully equipped emergency hospitals are also offered in this platform and are thus requested in this simulation. The registered end user can click on the Emergency Hospitals button (see Figure 1) and is seeing a description of the product and the possibility to send an inquiry.

As soon as the inquiry is sent, Hospitainer as responsible for the ‘Emergency Hospital cell’ immediate reacts to get in contact with the customer. After agreeing that a fully equipped emergency hospital has to be installed and Hospitainer directly orders the necessary medical products. An example of the result by this request is presented in Figure 2. This figure shows a fully equipped emergency hospital installed within a few days to replace a completely damaged hospital due to war. With this hospital, it is still possible to service the population who is still in the war-area.

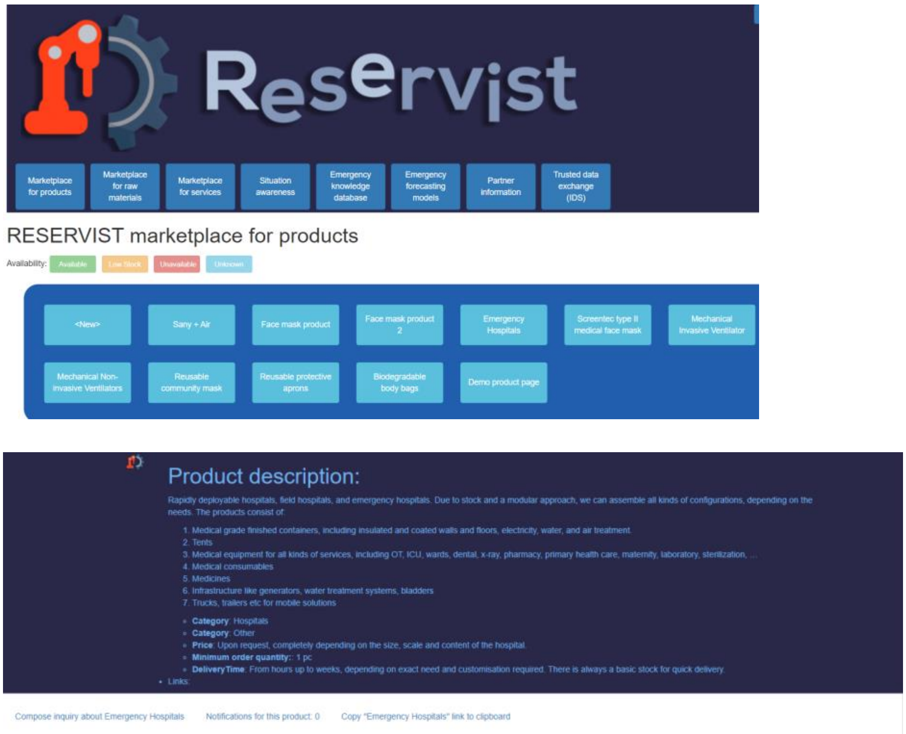

Figure 1. Reservist digital platform.

Figure 2. Field hospital built with containers.

Conclusions

A simulation on how the Reservist concept could work is presented by the simulation of an emergency situation where a field hospital was requested. The simulation showed that it is feasible to get the hospital installed within a few days at the required location in Europe and thus that Reservist is capable to respond rapidly to emergency situations.

Acknowledgements

This work was conducted within the Reservist project (https://cov-reservist.eu/) which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101016041.

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Reservist project: Blueprint for testing and certification of protective equipment in emergencies

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Keywords

certification, testing, standardization, protective equipment, emergencies

Introduction and methodology

This paper introduces a blueprint for efficient testing and certification in emergencies. Any product coming to the market must be tested and eventually certified compliant to the quality standards required for the product. During emergency situations, this process is even more crucial given that critical products must be supplied faster to the market to respond to the needs and demands of the emergency. Covid-19 was no exception. However, during this pandemic, the limited testing and certification capacity could not meet the high demand despite efforts from regulatory bodies, manufacturers, and testing and certification facilities. Therefore, the main pillar of this blueprint is to optimize the use of testing and certification capacity, especially regarding personal protective equipment and medical devices, in case of emergency. This goal is achieved by focusing on quality control before, during, and after manufacturing.

Results and discussion

Based on the lessons learned during the Covid-19 pandemic in relation to testing and certification of masks, accredited testing and certification capacity cannot increase to meet the demand in an emergency. The main reason is the cost related to being an accredited lab or a notified body. These costs include well-trained personnel, a quality management of the lab that can pass yearly audits from national accreditation bodies, and the financial cost related to the equipment, etc: being an accredited and/or notified body is a long-time investment and commitment to quality and this does not happen overnight. Therefore, the available capacity of accredited labs must be allocated carefully to be able to meet the demand for accredited testing/certification in emergencies. The blueprint (Figure 1) aims at being a one- stop-shop for local manufacturers, where they have one entry point (a local testing/certification facility) for all their testing and certification services in case of emergency. In brief, the blueprint comprises three stages. First, at production level, the manufacturer should ensure that the starting materials are adequately tested and check that the production follows the quality requirements for the desired final product. The final product would then be pre-screened either at the manufacturer's site or at an external non-accredited testing facility. If the product passes the pre-screening tests, it can be sent to an accredited testing lab for further testing. Finally, if applicable, the testing results may be submitted to a notified body for certification of the product.

Conclusions and perspectives

This paper introduces a testing and certification blueprint with quality control as its pilar. The aim of this blueprint is to optimize the use of testing capacity during emergencies. Beyond testing and certification, sustainability and circular economy of products should also be considered. Of course, in emergencies such as the start of Covid-19 pandemic, the main goal is to save lives and sustainability and circular economy are overlooked. Nonetheless, when possible, the eco-design should be performed during product design and manufacturing phases. This enables to take maintenance and end-of-life issues into consideration.

Acknowledgements

This work was conducted within the Reservist project (https://cov-reservist.eu/) which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101016041.

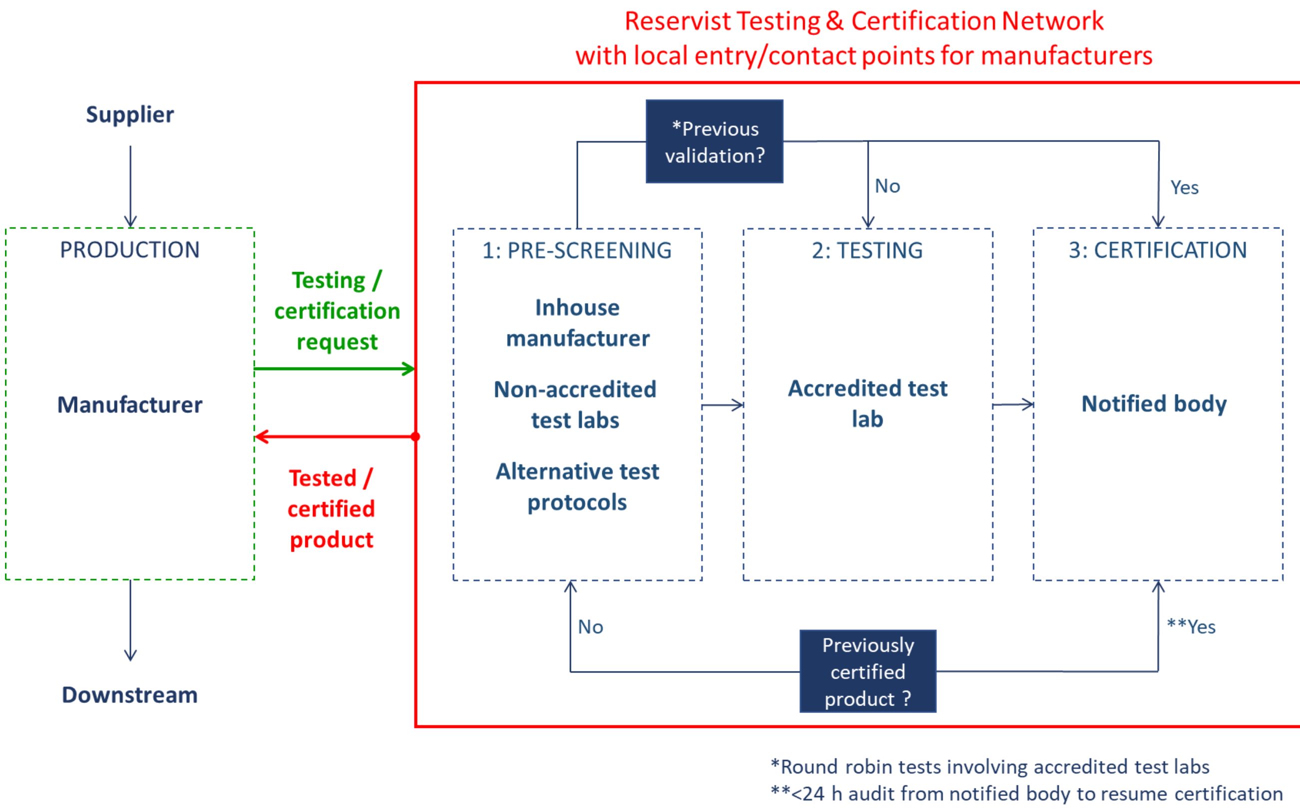

Figure 1. General testing and certification blueprint.

Reservist project: Re-design of textile protective equipment for production via alternative lines in case of spiking demand times

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Keywords
Reusable face masks, medical gowns, biodegradable body bags

Introduction

During the first wave of the COVID-19 pandemic the world faced a severe shortage of various textile protective equipment such as face masks, medical gowns, and body bags. To avoid similar situations during future events, it is important that extra production capacity can be created in spiking demand times and that alternative productive equipment can be supplied in case that conventional materials are not available anymore. For example, face masks are, as well-known by now, vital means in limiting the spreading of COVID-19. When it comes to spikes in demand and related emergency production, the challenge is that their production requires specific melt blown non-woven materials as barrier material, which relies on dedicated (large, expensive) manufacturing equipment. Moreover, they are typically single use, meaning a very large need, e.g. UNICEF reports a need of over 2 billion masks[1].

Therefore, in this contribution, we present the redesigning of facemasks and gowns in order to 1) make them reusable to reduce the need, and 2) that they can be produced on existing (tweaked) European manufacturing lines which are normally producing other textiles in non-crisis situations. Also, the development of alternative body bags is presented. Body bags are a vital means to prevent any diseases spreading from deceased persons. These products are currently based on non-biodegradable plastics (typically PVC and PE), so once these bags are in use under the ground, they stay there for many years as no degradation occurs. The pandemic demonstrated a need for qualitative and more sustainable body bags that are rapidly available in case of an emergency.

Methods

For the face masks, new polymer fibres were selected and a geotextile manufacturing line was modified to produce needlefelt nonwovens suitable for making face masks. In total, 12 different needlefelt nonwovens were prepared and fully tested. The breathability and bacterial filtration efficiency was determined to evaluate the quality of the masks. For the reusable aprons, coated textiles were prepared via transfer coating.

The aerosol barrier (ISO/DIS 22611)[2] and virus barrier (ISO 16604)[3] properties were determined and the breathability was tested according to ISO 11092[4].

Different biodegradable polymers were selected for the development of biodegradable body bags. It was first investigated if these polymers are processable on the production lines of SIOEN and if additives are required to improve the processability. In a second step, the mechanical properties were characterized and foils were put in compost to determine the biodegradability (EN 13432[5]).

Results and discussion

Figure 1. Face mask based on needlefelt.

Figure 2. Reusable gown.

Face masks based on needlefelt

The average differential pressure of this mask as presented in Figure 1 is around 22 Pa/cm² and this passes the performance requirement of medical masks. However, the BFE value of the best sample is still too low (around 80%) to be suitable as a medical mask. This means that these masks are not suitable as medical masks, but can still be used as community masks to provide at least a minimal protection.

Reusable gowns

A picture of the gown is presented in Figure 2. The developed gown is fully waterproof (> 2000 mm according to ISO 20811) and is still waterproof after 25 washings at 95°C in SIOEN's testing lab. The gown has excellent barrier properties as it obtained a class 6 rating for virus barrier properties according to ISO 16604[3] which is the highest classification, and it has a class 3 classification for the resistance against penetration by a bacteria infected aerosol according to ISO/DIS 22611[2]. The gown is also comfortable to wear because the measured RET value is 15 $m^2 \cdot Pa/W$, and this means that the gown has a good breathability.

Body bags

After the first processing trials it was clear that new elements were needed to change the existing extruder screw configuration in order to obtain both a stable process with flat current-curve and sufficiently low temperature of the melt strand coming out of the die to avoid sticking on the rolls of the calendaring unit. After this was solved it was possible to obtain a biodegradable material for body bags (tested) with good mechanical properties. Figure 3 shows a prototype of the body bag that was developed.

Figure 3. Prototype of a biodegradable body bag.

Conclusions

Three different alternative protective products were presented that can avoid shortage of crucial protective equipment during health crises. These products are reusable face masks based on needlefelt nonwoven, reusable medical gowns and biodegradable body bags. The developed reusable face masks do not comply to the medical face mask requirements because of the limited BFE values (appr. 80%), but can be used as community masks in spiking demand times. Reusable gowns with good virus barrier properties and high breathability, and biodegradable body bags with good mechanical properties were also developed.

Acknowledgements

The presented results are obtained in the Reservist project (https://cov-reservist.eu/) which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101016041.

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How do disinfecting wipes impact the barrier performance of protective clothing?

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Keywords

protective clothing, gowns, coveralls, barrier resistance, wiping, decontamination

Introduction

During outbreaks, epidemics, and pandemics, healthcare personnel (HCP) are on the front line of disease containment and mitigation. Gowns and coveralls are essential elements of HCP's personal protective equipment (PPE) to reduce or eliminate the transmission of contaminated fluids to the HCP's skin or inner clothes. Therefore, protective clothing serves an important role in minimizing HCP risks and is in high demand during public health emergencies. Because PPE demand can exceed supply during these emergencies, various public health strategies, including extended use and limited reuse of PPE, have been developed and employed to reduce the rate of PPE consumption as supply dwindles (1). Also, localized soil removal via application of disinfecting wipes is a common practice employed when a change of clothing is not possible due to time constraints, although it may not be suggested by manufacturers. However, it is unknown how this wiping action impacts the barrier resistance (resistance to liquid and viral penetration) of protective clothing.

Methods

This study investigates the impact of disinfecting wipes on the barrier resistance of protective clothing. Nine disposable protective clothing models with varying barrier resistance claims (2) were tested for water resistance, using impact penetration (3) and hydrostatic pressure (4) test methods before and after the brief application of wipes after brief application of disinfecting wipes using 10 specimens/model using the fabrics cut from different garments. Samples were conditioned for a minimum of four hours before testing, in compliance with ASTM D1776 Standard Practice for Conditioning and Testing Textiles (5) and tested immediately after a gentle and brief application of wipes on the face (outside) of the fabrics. Samples included isolation gowns, surgical gowns, and coveralls that are commonly used by healthcare personnel in the U.S. Two types of widely used disinfecting wipes with different chemical compositions were used. Tests were repeated after drying the fabrics.

Results and discussion

We found that the hydrostatic resistance of most of the fabric types, except laminated and poly-reinforced fabrics, was severely impacted by wiping for both wipe types and before and after drying. Level 2-3 gowns barrier resistance fell below the requirements of the ANSI/AAMI PB70 standard, which classifies protective clothing used in healthcare facilities based on their liquid barrier performance (2).

Conclusions

We concluded that wiping gowns and coveralls should be avoided as much as possible when liquid and viral penetration resistance is needed since end users may not be able to identify the type of the protective clothing fabrics and disinfecting wipes. End users should consult with the manufacturers regarding the wipe use. This study provides important implications for clinical practice as it highlights that wiping significantly reduced the barrier resistance of several gown models. Findings are especially important in light of pandemics since wiping could be considered as a practice to disinfect protective clothing due to the severe PPE shortages.

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DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH, CDC.

Development of an animatronic headform test method to evaluate the efficacy of barrier face coverings

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Keywords
filtration, fit, advanced headform, face coverings, COVID-19

Introduction

Medical masks and barrier face coverings have been used by the public as a method of source control. These products offer variable efficacy depending on their material, fit to the face, and the environment in which they are worn. Conflicting performance standards used to evaluate respirators, medical masks, and now barrier face coverings may confuse manufacturers and end users. Testing parameters including the flow rate, particle charge, and particle size vary significantly between methods which can affect the reported performance (1). Recent studies and standards tend to evaluate these products at the material level or as a sealed product which does not account for leakage around the perimeter of the barrier due to poor fit that can significantly reduce filtration (2). This research focused on developing a system-level method to realistically assess the performance of these products that are not designed to seal to the face. An advanced animatronic headform with breathing and movement capabilities was used to evaluate the total filtration efficiency (TFE) of several respiratory devices, medical masks, and barrier face coverings. The term TFE is used to describe the systemic measurement of filtration efficiency that incorporates both fit and material performance into the final filtration value.

Methods

The i-bodi Fully Animatronic Respirator Testing Headform was used to develop a method to evaluate the efficacy of barrier face coverings as worn. Initially, six commercially available products were evaluated with a baseline method to determine the effects of different experimental parameters on filtration. An unneutralized, polydisperse NaCl aerosol was generated inside the chamber using a TSI Single-Jet Atomizer 9302. Two Fluke® 985 particle counters measured the differential particle counts at 0.3, 0.5, 1, 2, 5, and 10 µm inside and outside the sample each minute to calculate the percent TFE. Each test cycle consisted of a pair of test segments. The static segment consisted of five minutes of stationary breathing. After a ten-minute break, the dynamic segment ran through five minutes of a programmed movement protocol consisting of a minute of head shaking, nodding, biting, wobbling shoulder to shoulder, and one last minute of stationary breathing. Ten replicates of this test cycle were completed for each sample by three operators at two different volume flow rates of approximately 16 L/min and 28 L/min sinusoidal breathing. After analysis, the sample selection was expanded to incorporate a wider range of products that were tested with the baseline method at the 16 L/min breathing rate.

The optimized method used the same system with some adjustments to the testing parameters to evaluate twelve different samples including a NIOSH-certified N95, two GB2626-2019 compliant KN95s, two ASTM F2100-21 compliant medical masks and a third medical style mask compliant to ASTM F3502-21, and six different styles of barrier face coverings. The optimized testing was carried out in a controlled environmental chamber at 20 ± 2°C and 65 ± 5% relative humidity. A TSI Particle Generator 8026 ran continuously to generate a polydisperse NaCl aerosol to fill the chamber. A combined protocol was designed to replace the two static and dynamic segments in the baseline method. The new ten-minute test consisted of two minutes of stationary breathing followed by a minute of each of the movements bite, head nod, and head shake. These three movements were repeated for another three minutes before ending the test with two more minutes of stationary breathing. The breathing protocol was adjusted to approximately 15 L/min based on the minute volume to perform a light workload for a healthy medium sized adult (3). A single operator conducted all ten replicates for each sample type.

Results and discussion

The baseline headform method was able to differentiate between samples clinically above a 5% difference and statistically where $P < 0.05$. The respiratory flow rate, testing duration, and operator were shown to significantly impact filtration while the influence of movement was less conclusive. The variance component estimates confirmed that the initial method had good repeatability and reproducibility. From this analysis, an optimized headform method was developed to reduce the variability within samples. The most significant change in the optimized method was the controlled environmental conditions. Other testing parameters were found to have less of an influence on TFE than previously observed. The condensed protocol was still able to statistically differentiate between samples across the three product groups. The comparison between the baseline and optimized methods found the optimized method had lower TFE and smaller standard deviations across all twelve products as shown in Figure 1. The variance components confirmed that sample type was responsible for the majority of the variance with notably lower unexplained error in the method that demonstrated the improved repeatability in the optimized method. The more moderately performing products like the medical masks maintained higher data spreads due to the variability of fit achieved on the headform.

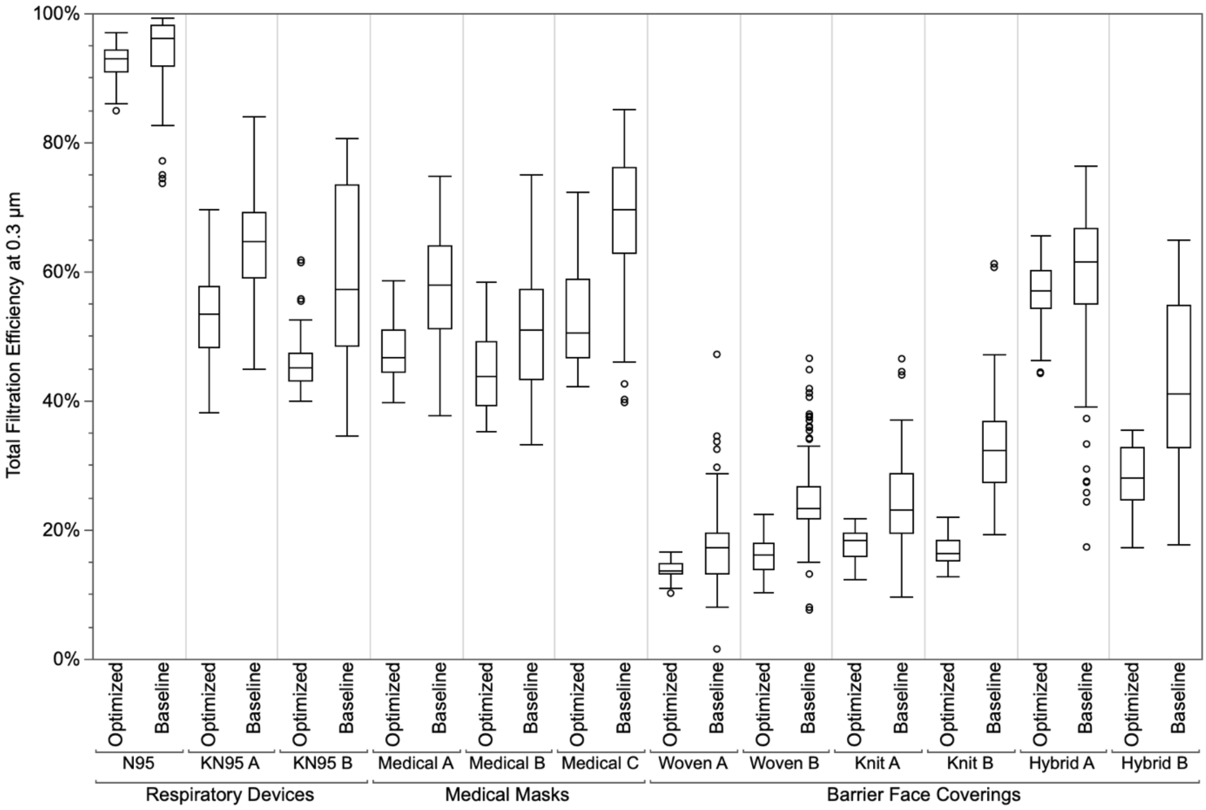

Figure 1. Box plot for TFE at 0.3 µm comparing the optimized and baseline headform test methods by sample.

Conclusions

This study offered an alternative method to traditional material and system-level evaluations that was able to realistically assess the performance of barrier face coverings and other products on a headform. The optimized method is a repeatable test that can more reasonably evaluate the total filtration efficiency and inward leakage of these alternative products. However, there is still room for further development. The ASTM F3502-21 Standard Specification for Barrier Face Coverings requires both filtration efficiency and breathing resistance measurements to evaluate protection and comfort (4). Ultimately, the optimized headform method should be able to evaluate both filtration and breathability in one protocol as well. Future work will work towards incorporating differential pressure measurements on the headform and conducting a validation study with another operator to determine the reproducibility of the proposed method.

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Filtration performance of cloth masks with different air permeability worn over a surgical mask

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Keywords
particle filtration, surgical masks, cloth masks, respiratory protection, air permeability

Introduction
In the event of a pandemic caused by airborne pathogens, there is a great need for respirators to provide protection not only to healthcare workers but also to the public. In the US, healthcare workers are assigned medical facemasks (surgical masks) when they are not at risk of direct exposure to infectious diseases. For those at risk of exposure, respiratory protection is required, and healthcare workers should be using US-certified N95 or better masks[1]. With the high demand during a pandemic, a shortage of respirators is inevitable and requires prioritization of respirators for healthcare workers. Yet, when the shortage is prolonged, some healthcare workers may have to use surgical masks due to low N95 respirator supplies. Moreover, cloth masks have been advised to be worn over the surgical mask[2,3]. However, there are no standardized/certified cloth masks, unlike respirators, and the selection of proper cloth masks remains unknown. Herein, we investigated the effect of the type of cloth mask worn over a surgical mask on the total particle filtration efficiency (PFE) at 0.3 µm, which is known as the most penetrating particle size. We concluded that a properly fitted cloth mask worn over a surgical mask could improve total PFE regardless of its air permeability.

Materials and Methods
Five fabric types were used to prepare the cloth masks listed in Table 1. The CDC DIY mask was remade with a nose bridge and size adjusted to the headform and was labeled "CDC DIY mask (adjusted)".

Table 1. Properties of Cloth Masks.

Cloth Mask	Fabric Description	# Of Layer	Mask Shape	Air permeability ($ft^3/min/ft^2$)
S-33	33 tex silk plain knit	2	Cup	177 ± 7
C-33	33 tex cotton plain knit	2	Cup	88 ± 5
C-20	20 tex cotton plain knit	3	Cup	61 ± 2
Cx2-40DS	20 tex cotton spandex plain knit	1	Cup	15 ±1
CDC DIY	20 tex cotton plain knit	2	Flat	43 ± 1

A headform was used for testing to measure the PFE of masks at 0.3 µm. The test setup consisted of a headform, two particle counters, a digital breathing machine with a control computer, and a TSI particle generator. 2% NaCl aerosols were generated by the particle generator. The headform testing was conducted in a climatic chamber at 20 ± 2℃ and 65 ± 5% relative humidity. Breathing frequency was set at 15 breaths per minute with a face velocity of 3.5-4 cm/s. The breathing action was the integration of inhalation and exhalation. The particle counters simultaneously recorded the total number of particles inside and outside the headform for each minute cycle. In addition, the air permeability of the multi-layer fabrics used in the preparation of cloth masks was measured according to the ASTM D737-18 standard.

Results and Discussion
N95 respirator and surgical mask performed 83% and 56% PFE on the headform, respectively, clearly showing the effects of fit as has been described in the literature[4]. When the surgical mask was sealed on the headform, it reached 90% PFE. The large increase in the PFE with sealing indicated the strong negative impact of the loose fit of the surgical mask. However, up to 76% PFE with a much smaller variation was observed when a cloth mask was worn over the surgical mask, regardless of the mask type. The only exception was the CDC DIY mask (see Figure 1). The CDC DIY mask was the only one with easily visible large gaps, especially around the nose. Accordingly, these results supported the necessity of a well-fitting cloth mask to improve the total PFE when worn over the surgical mask. Moreover, C-33, C-20, and Cx2-40DS cloth masks performed with a similar increase in the total PFE despite the differences in their air permeability. Therefore, our results suggested selecting a cloth mask with a high air permeability to prevent breathing difficulties while still having a high PFE.

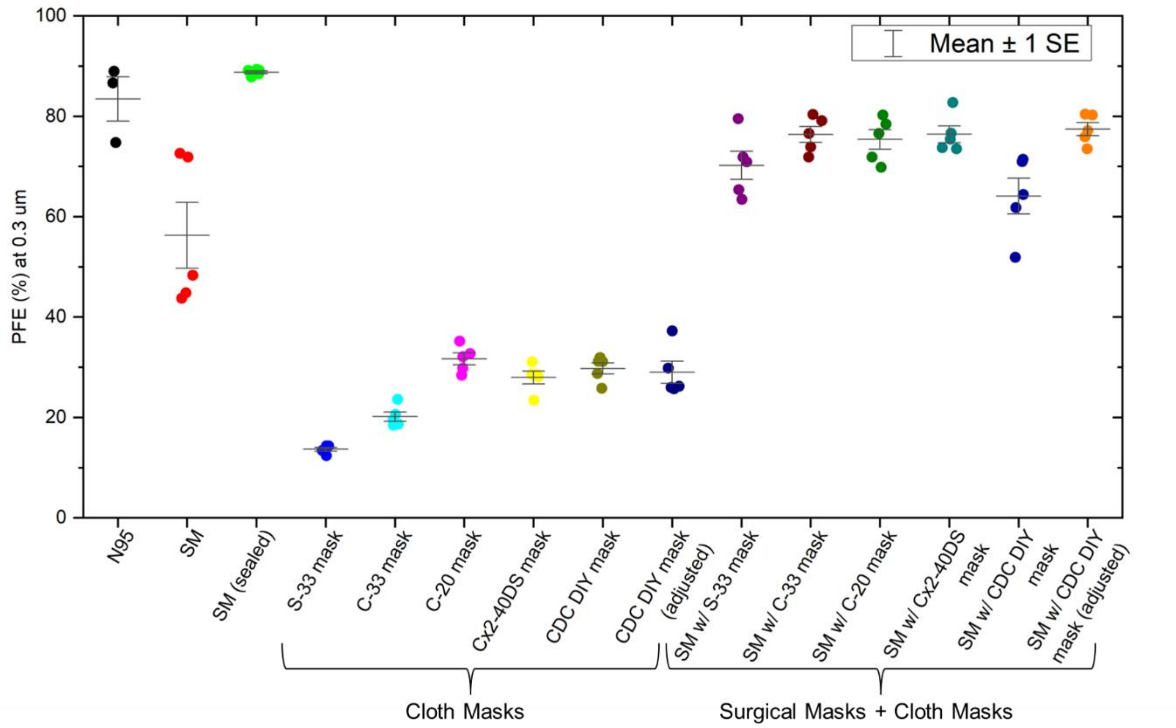

Figure 1. Headform testing results of masks. "SM" refers to a surgical mask.

Conclusions

The filtration performance of a surgical mask is highly dependent on the mask fit. Therefore, the fitting of the surgical mask must be improved to achieve an acceptable level of respiratory protection. Wearing a cloth mask over the surgical mask can limit leak generation and improve the total PFE. However, the cloth mask should fit well on the wearer's face to enable a positive effect. Moreover, even though a well-fitted cloth mask may improve the total PFE regardless of the fabric type, the air permeability of the mask should be considered to limit the decrease in breathability.

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Poster session

Ergonomic and performance differences between firefighter protective clothing systems

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Keywords
fire and rescue services, physiological measurements, subjective responses, personal protective equipment, performance evaluation

Introduction
Firefighters are exposed to various forms of hazards such as extreme heat, electrical hazards and cold. The protective clothing system (PCS) or personal protective equipment (PPE) is essential for firefighters for protecting them against those hazards and for optimal performance. Recently, a new PCS with and without outer jacket was introduced to the Dutch Firefighters (Figure 1). The main objective of this study was to determine the ergonomics and performance differences between a T-shirt and shorts (CS1) and the new firefighter system without (PCS2) and with an additional jacket (PCS3) using an ergonomic test battery based on Havenith and Heus (1). A secondary objective was to provide recommendations for optimizing the ergonomic test battery.

Figure 1. The two new clothing systems CS2 (left) and CS3 (right) investigated in this study.

Methods
Six males (26.8±11.4 year) performed 12 consecutive physical firefighter task related- and 9 stretching exercises in three CS in balanced order. Skin temperature (T_{skin}), rectal temperature (T_{rectal}), heart rate (HR), mean body temperature (T_{body}), performance time/distance and rating of perceived exertion, thermal sensation, comfort, skin humidity, fit and reach scores were determined. Mean values and increase over time (Δ-values) were calculated.

Results
Table 1 shows an overview of the results. ΔT_{skin} differed between CS: -0.3±0.6°C (CS1), 0.6±0.3°C (PCS2) and 0.8±0.5°C (PCS3) ($p<0.001$) as did ΔT_{body}: -0.07±0.11°C (CS1), 0.12±0.08°C (PCS2) and 0.15±0.12°C (PCS3) ($p<0.001$). ΔT_{rectal} was lower for CS1 (-0.03±0.06°C) than CS2 (0.00±0.07°C) ($p<0.001$). For ΔHR, CS1 (6±15 bpm) and PCS2 (7±21 bpm) were lower than PCS3 (15±19 bpm) ($p<0.001$).

Donning (12s) and doffing (7s) were faster ($p<0.05$) in PCS2 compared to PCS3. Ladder climbing was 4s faster ($p<0.05$) in CS1 compared to PCS3. The remaining performance- and all subjective measures of the physical exercises showed no significant differences. The subjective elbow mobility fit and reach score was better ($p<0.05$) for CS1 compared to PCS3. The other stretching measures gave no differences.

Table 1. Mean (M) and standard deviation (SD) of the physiological and performance measures (N=6). In superscript = clothing system number with which a significant difference exists.
***! = significant main effect, but no significant post hoc effect; * = significant effect <0.05; ** = significant effect <0.001; a = nonparametric; E = exercise.**

	Clothing system					
	CS1		PCS2		PCS3	
	M	SD	M	SD	M	SD
Physiological measures						
T_{skin} (°C)**	30.6 [23]	1.1	32.7 [1]	0.7	32.6 [1]	0.7
T_{rectal} (°C)**	37.8 [3]	0.2	37.8 [3]	0.2	37.7 [12]	0.3
T_{body} (°C)**	36.4 [23]	0.3	36.8 [13]	0.2	36.7 [12]	0.3
HR (BPM)**	104 [23]	28	116 [1]	30	113 [1]	28
ΔT_{skin} (°C)**	-0.26 [23]	0.63	0.60 [13]	0.31	0.81 [12]	0.46
ΔT_{rectal} (°C)**	-0.03 [2]	0.06	0.00 [1]	0.07	-0.01	0.06
ΔT_{body} (°C)**	-0.07 [23]	0.11	0.12 [13]	0.08	0.15 [12]	0.12
ΔHR (BPM)**	6.2 [3]	15.4	6.6 [3]	20.9	14.5 [12]	19.2
Performance measures						
E1 donning (s)*			46.1 [3]	7.5	57.6 [2]	6.8
E2 timed up and go (s)	4.4	0.8	4.7	1.0	4.7	1.0
E3 stand-and-reach (cm)	104.7	20.8	99.0	22.5	91.6	16.1
E4 sit-and-reach (cm)*![a]	30.7	5.1	29.8	3.7	27.2	4.3
E5 sergeant jump (cm)	276.3	11.1	276.8	11.7	273.6	12.9
E6 manikin dragging (s)	10.6	1.9	10.9	1.7	10.7	1.7
E7 balance plank (s) [a]	8.9	1.5	9.4	1.6	9.9	1.4
E8 firehose (s)*!	28.5	5.2	31.5	4.3	36.4	5.2
E9 ladder climbing (s)*	27.6 [3]	2.8	30.7	4.2	31.4 [1]	2.5
E10 over and under obstacle (s)	27.3	4.2	28.4	3.1	28.9	2.9
E11 crate lifting (s)	21.4	3.0	21.8	3.3	22.2	2.7
E12 doffing (s)*[a]			23.5 [3]	6.5	30.9 [2]	5.3

Discussion

As expected, thermal strain was higher in PCS than CS and thermal strain was higher when wearing the PCS with jacket compared to the system without. These observations are in line with results of a study that investigated the thermal insulation of PCS2 (0.361 m^2K/W) and PCS3 (0.403 m^2K/W) (2). This supports the finding of the higher ΔT_{skin} and ΔT_{body} of PCS3 compared to PCS2.

The rating of stretching exercises did not discriminate between systems. The stretching exercises may become more useful if objective measurements would be added. Tochihara, Lee and Son (3) write in their review that range of motion is a sensitive and valid method to assess mobility. This can be measured for example using goniometers.

Conclusions

The two firefighter PCS differ in heat strain, as can be determined using the measures ΔT_{skin}, ΔT_{body} and ΔHR. The use of ΔT_{body} for fire fighter clothing evaluation is recommended since it gives the best representation of body heat storage. Donning and doffing was longer in PCS3 since this system had an extra jacket to put on or off. Subjective movement restrictions between the firefighter PCS were not experienced.

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Immune age: the feminine side of firemen?

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Keywords
firefighter, immune system, aging, sex

Introduction

Physical demands arising from heavy work with protective equipment, mental stress as well as exposure to environmental hazards experienced in firefighting operations pose health risks affecting the immune functions of firefighters (1). On the other hand, a robust immune system is beneficial for sustaining work ability in good health, thus enhancing the operational readiness of an aging workforce. The concept of immune age aims at quantifying the decay in functions of the immune system with individually varying progression in the elderly, which does not necessarily parallel chronological age (2). Referring to previous results (3) indicating that immune age contributes to explaining the inter-individual variability of the age-related decline in cardiorespiratory fitness, it was the objective of this study to compare the immune age of a group of professional firefighters to a reference sample drawn from the general adult population.

Table 1. Characteristics of male and female participants in the reference and firefighter groups.

Characteristic	male Ref, N = 235[1]	female Ref, N = 327[1]	male FF, N = 84[1]	female FF, N = 7[1]
Age (years)	53 (33, 64)	53 (32, 62)	40 (31, 53)	30 (30, 40)
Body height (m)	1.80 (1.76, 1.86)	1.67 (1.63, 1.72)	1.83 (1.78, 1.88)	1.71 (1.70, 1.74)
Body mass (kg)	85 (76, 95)	68 (60, 79)	86 (80, 95)	65 (64, 67)
BMI category				
normal	91 (39%)	179 (55%)	30 (36%)	6 (86%)
overweight	102 (43%)	91 (28%)	46 (55%)	1 (14%)
obese	42 (18%)	57 (17%)	8 (9.5%)	0 (0%)
Regular physical activity				
none	18 (7.7%)	29 (8.9%)	2 (2.4%)	1 (14%)
1–2 times per week	80 (34%)	123 (38%)	24 (29%)	1 (14%)
3–5 times per week	99 (42%)	130 (40%)	54 (64%)	4 (57%)
6–7 times per week	38 (16%)	45 (14%)	4 (4.8%)	1 (14%)
Non-smokers	148 (63%)	240 (73%)	50 (60%)	6 (86%)
With chronic disease	65 (28%)	136 (42%)	15 (18%)	0 (0%)
Immune age *IMMAX*	0.49 (0.41, 0.58)	0.45 (0.36, 0.55)	0.40 (0.34, 0.48)	0.37 (0.33, 0.47)

[1]Ref: reference group; FF: firefighter group; BMI: body-mass index (=mass/height^2);
continuous data summarized by median (25th, 75th percentile); categorical data by frequency (%)

Methods

In this cross-sectional study, blood samples taken from 84 male and seven female professional firefighters 21–58 years of age were analysed by flow cytometry to determine peripheral blood mononuclear cell frequencies (4), which were then used to calculate the IMMune Age indeX IMMAX (3), ranging from 0 to 1, based on a comprehensive immune age metric (2). These values were compared to corresponding measurements of a reference sample comprising 327 females and 235 males aged 18–88 years recruited from the general regional adult population. Further characteristics were obtained by a questionnaire as presented by Table 1.

We compared the IMMAX values between the different groups while adjusting for chronological age by ANCOVA, disregarding the data from the female firefighters due to the small sample size.

Results

ANCOVA results revealed a significant increase of the immune age score IMMAX with chronological age ($p<0.001$), with averaged slope of 0.43% per year that was almost parallel between the three groups, as indicated by the non-significant interaction of age with group ($p=0.71$). On average, IMMAX differed between the three groups with statistical significance ($p<0.001$). Post-hoc tests showed that in the reference group, immune age scores for females were significantly ($p<0.001$) lower compared to males, with the difference of 3.3% corresponding to a horizontal shift of eight years of life (Figure 1). Likewise, firemen‘s IMMAX scores were on average by 4.1% lower compared to values for males from the reference group (p=0.007), whereas the corresponding difference between firemen and the female reference group was not statistically significant (p=0.79). Interestingly, the regression line of immune age related to chronological age for firemen was almost identical to the corresponding line for females from the reference group, with similar Pearson correlation coefficients between 0.5–0.6 for the three groups (Figure 1).

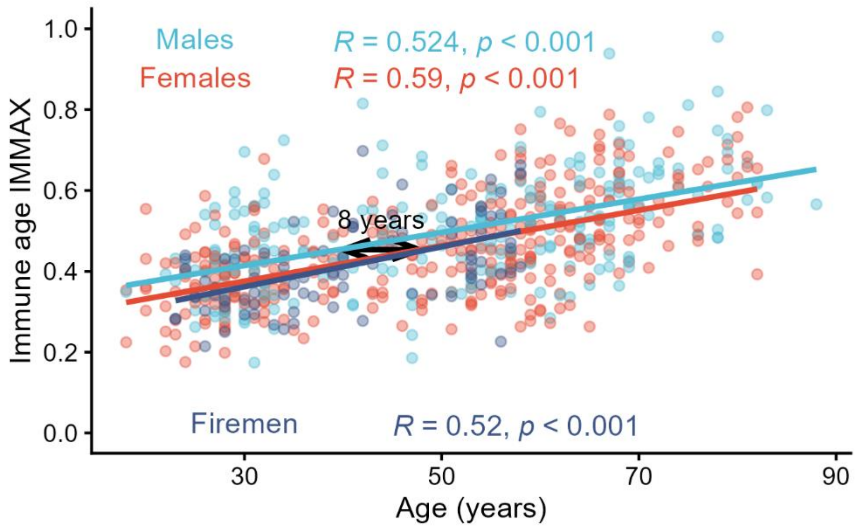

Figure 1. Immune age score IMMAX related to chronological age with regression lines, correlation coefficients (R) and p-values for firemen compared to males and females of the reference group.

Discussion and conclusions

Confirming earlier findings (2, 3), the lower immune age for females compared to males may be indicative for a stronger female immune system. Together with the previously established association of increased immune age with lowered cardiorespiratory fitness (3), this might suggest a higher level of physical fitness for firefighters compared to the general population as probable explanation for the 'feminine' development, i.e. the younger immune age in relation to the chronological age of firemen in this study.

Due to the small sample size, this study could not provide any robust conclusion about female firefighters. Thus, strengthening their participation in prospective studies aiming at the verification and health implications of our results, e.g. for including immune age as biomarker in medical prevention (1), is mandatory.

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3D virtual model construction of filter membrane and multilayered fabric structure of firefighters' particulate hoods to simulate particle loading behavior

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Keywords

particulate hood, particulate filtration efficiency, air permeability, simulation, optical microscopy

Introduction

The 3-layer particulate hood generally consists of an outer woven fabric layer, an inner membrane-coated particle blocking layer (filter layer), and an inner woven fabric layer. While the existing fire-fighter hood has a double-layer structure of flame-retardant knit material, the 3-layer particulate hood has an extra layer in the middle which is laminated by filter membranes. Particle load simulations based on a 3D virtual fabric structure characterized by X-ray CT may facilitate a geometrical understanding of the behaviour of particles against fire-fighter hoods and suggest improved structures. However, the membrane in the middle layer is composed of fine fibers so it is difficult to acquire an exact virtual model of it. To solve this problem, in this study, the membrane of the layer was assumed to be porous solid using a filter simulation, and the structure of the existing layers was virtually constructed by the Micro-CT to explore and verify conditions in a virtual environment that satisfies the actual air permeability conditions. After establishing the structure of the filter membrane through this process, changes and trends in the particle filtration efficiency of the entire 3-layer fabrics can be analyzed according to changes in the particle filtration efficiency of the filter membrane.

Methods

In the virtual environment modelling, the 3-layer fabric's air permeability was first measured, and then the optimal air permeability of the filter layer was defined through the parameter optimization process in the virtual environment. Thereafter, the filter layer, the outer, and the inner layer were implemented by Micro-CT (ZEISS Xradia 510 Versa) to derive a virtual model in the simulation software, GeoDict. The air permeability performs as a validation parameter between the 3-layer fabric and the 3D virtual fabric. After validating the virtual model with air permeability, the particulate filtration efficiencies of the entire 3-layer fabric are generated based on the filter layer's particulate filtration efficiency changes. Fabric's particulate filtration efficiency performance and evaluation method refer to ASTM F2299 (1).

Results and Discussion

The average air permeability of the 3-layer fabric and filter layer is 3.6 mm·s^{-1} and 1.8 mm·s^{-1}, respectively. The membrane of the filter layer was implemented based on air permeability under porous solid conditions, and the thickness of actual 3-layer fabric and filter layer was 1.55 mm and 0.42 mm. The filter layer's air permeability was compared with the actual air permeability value through the process of deriving the optimum value while optimizing within the air permeability range (e^{-1} to e^{-15}) of the porous solid layer created in the virtual environment. Additional particle film efficiency will be measured under simulated results.

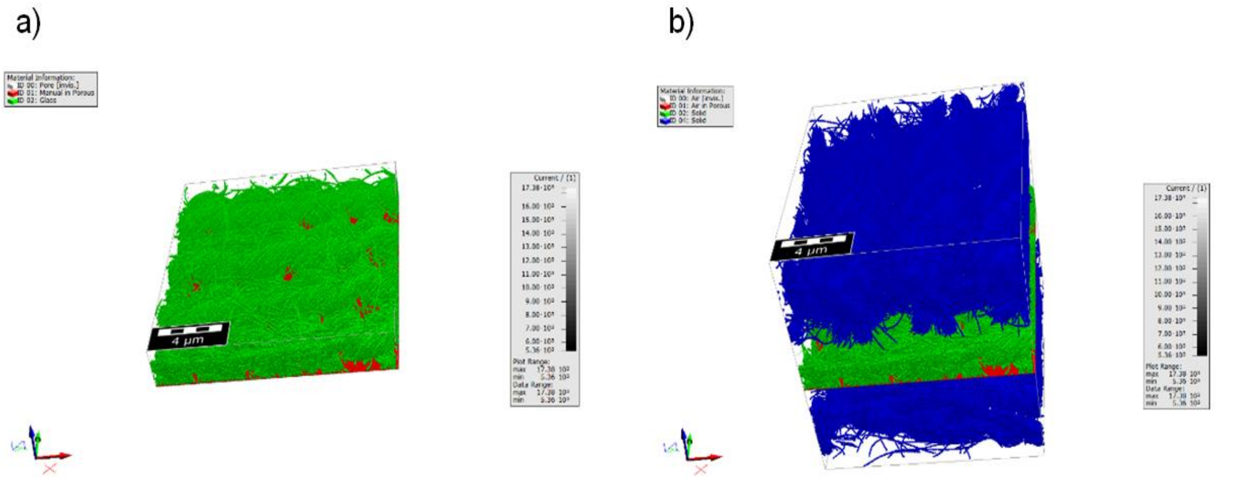

Figure 1. 3D virtual fabric structure; a) Membrane-coated particle blocking layer, b) 3-layer fabric.

Conclusions

The structures of the filter layer and the 3-layer fabric of the particulate hood were derived through the simulation process, and the air permeability of the virtual model was compared and verified with the actual performance to acquire an optical membrane layer structure. This modelling is to derive particle filtration efficiency, which is one of the performance indicators of particulate hoods, and this virtual structure can be used as a pilot test for conditions that satisfy the criteria for particle filtration efficiency of actual products. To expand our research, we are planning to change the conditions of the film's particulate filtration efficiency to explore the changes and trends of the 3-layer particulate hood's particulate filtration efficiency virtually.

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Degradation in tensile strength of flame-retardant textiles after exposure to high temperature and high humidity and suggestions for an accelerated hydrolysis test development

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Keywords
hydrolysis, degradation, tensile strength, flame-retardant textile, reliability assessment

Introduction
To prevent serious burn injuries, various occupations are required and recommended to wear protective clothing made of flame-retardant textiles (e.g. combat/police uniform, aviation garment, workwear for industrial workers). The common characteristics of their working environment possess not only the existence of heat and flame but also occasionally high humidity mainly due to workers' heavy perspiration in the heat stress. It could result in the hydrolytic degradation of fibers can occur. Aramid, which is a well-known fiber showing long-term heat and flame resistance, is decomposed through amide bond hydrolysis reaction, especially in the presence of acid or base[1]. Flame-retardant rayon, which is frequently used in combination with aramid to provide better wear comfort, is known to be vulnerable to moisture because cellulose is decomposed into short fibers in response to water. Degradation of textiles can result in discoloration as well as a reduction of strength properties. In the current study, we first aimed to compare the reduction rate of tensile property of flame-retardant textiles with different blending percentages of fire-retardant viscose rayon and aramid. Through this process, in the final step of this study, the authors intended to suggest an accelerated hydrolysis test protocol to calculate their lifetime.

Methods
Two different textiles were used in these experiments. The first one was made of 40% of Aramid and 60% of fire-retardant viscose rayon (240 g/m^2). The other one was made of 100% aramid fiber (195 g/m^2). Specimens were laundered 5 cycles as the washing procedure 6N as noted in ISO 6330:2012[2] and dried. They were, thereafter, placed inside a chamber controlled to 160 ^{o}C and 100%RH for 12 and 48 hours. Tensile strength on the three textile specimens in both warp and weft direction were tested using a tensile tester. The reduction of tensile strength was compared with non-aged specimens.

Results and discussion
The tensile strength of 100% aramid was decreased to 12% and 51% after 12 hours and 48 hours exposures, respectively in the warp direction, while in the weft direction, it decreased to 26% and 69% after 12 and 48 hours, respectively. The degradation was greater in the aramid and viscose rayon blended textile. It showed ~45% and ~80% reduction of tensile after 12 and 48 hours, respectively in both weft and warp direction.

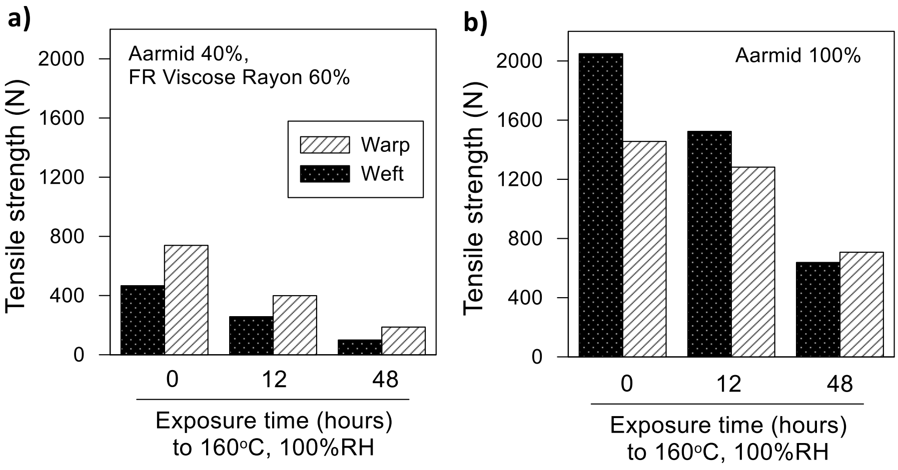

Figure 1. Changes in tensile properties of two flame-retardant fabrics after 0, 12, and 48 hours exposures under hydrolytic conditions.

Conclusions
The results showed that fire-retardant textiles lost their original tensile property after exposing to high temperature and high humidity. The reduction rate was much greater when the textile was blended with fire-retardant viscose rayon than 100% aramid fabric. These results imply that we could not guarantee the protective properties of industrial protective clothing composed of fire-retardant viscose rayon if the clothing is worn in hot and humid conditions. Reliability assessment methodology would be a useful tool to quantitatively

assess the stability against hydrolytic reactions during the long-term exposure time and allow us to calculate the expected lifetime with retaining sufficient tensile properties using an accelerated hydrolysis test protocol based on these experimental results. Further results and discussions would be presented at the conference.

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Cooling effects of a graphene oxide-coated sheet to alleviate exertional hyperthermia

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Keywords
hyperthermia, ice-sheet cooling, graphene-oxide coated textile, thermal conductivity, thermoregulation, skin temperature

Introduction
As the frequency of heat waves in the summer increases due to global warming, the heat-related injuries of military soldiers, agricultural and construction workers have been increasing. The first aid cooling treatment for hyperthermia in outdoor fields is vital. At present, the US Army and other military forces recommend ice-sheet cooling as an immediate treatment for exertional heat stroke in the fields (1, 2, 3). The ice-sheet cooling uses ice packs and water-soaked sheets (4, 5). However, because these wet sheets dry quickly over a hyperthermic body, improving the cooling power of wet-sheets is the major concern of the Korea Army. Graphene is a material known to have a very high thermal conductivity (about 4,000 $W·m^{-1}·°C^{-1}$), higher than copper (400 $W·m^{-1}·°C^{-1}$) and water (0.6 $W·m^{-1}·°C^{-1}$). We coated a fabric sheet with graphene oxide to increase its thermal conductivity. In this pilot study, we explored the cooling effects of the graphene oxide-coated sheet on reducing physiological and perceptual heat strain in a hot and humid environment.

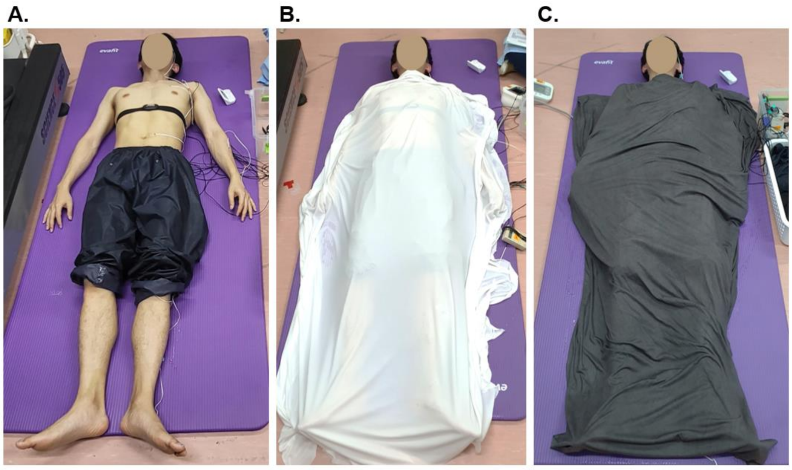

Figure 1. Control (A), Unprocessed condition (B), and Graphene condition (C) in the present study.

Methods
Six healthy males (26.3 ± 3.0 y in age, 173.8 ± 3.0 cm in height, 70.1 ± 8.7 kg in body mass, 21.9 ± 2.7 kg/m^2 in BMI, and 1.9 ± 0.1 m^2 in body surface area) participated in the following three conditions: (1) no sheet condition (“Control”), (2) cooling sheet condition (polyester 100% fabric, 160 × 180 cm, 166 g/m^2 in a dry condition) (“Unprocessed”), and (3) graphene cooling sheet condition (graphene-oxide-coated polyester 100% fabric, 145 × 198 cm, 167 g/m^2 in a dry condition) (“Graphene”). The temperature of the water applied to sheets was about 16°C and amount of water was 1.13 ± 0.05 kg per sheet. All trials were conducted at an air temperature of 33°C with 65%RH. Subjects performed aerobic exercise on a treadmill until their rectal temperature (*T*re) reached 38.5°C. Then exercise was stopped and we had subjects remove their T-shirts, caps, gloves, socks, and shoes followed by lying down on the mat. In the supine position, the water-soaked sheets were applied over the entire body except the head for 30-min for the Unprocessed and Graphene conditions, while the control was the same but with no sheet (Figure 1). The temperature and amount of water absorbed by the sheet were controlled as closely as possible. Rectal temperature (T_{re}), skin temperature (T_{sk}), and heart rate (HR) were measured every 5 s. Total sweat rates were calculated using changes in body mass. Thermal sensation (TS), thermal comfort (TC), and sweat sensation (SS) were obtained every 3 min. Mean T_{sk} was calculated using the following equation: $0.07T_{forehead} + 0.35(T_{chest} + T_{abdomen} + T_{scapula} + T_{lower\ back})/4 + 0.14T_{forearm} + 0.05T_{hand} + 0.19T_{thigh} + 0.13T_{calf} + 0.07T_{foot}$.

Results and discussion

When stopped exercise, T_{re} rose up to 38.9 ± 0.2, 38.9 ± 0.2, and 38.8 ± 0.2°C for the Control, Unprocessed, and Graphene conditions, respectively. $\bar{T}_{sk}$ was also elevated to 36.9 ± 0.3, 37.1 ± 0.4, and 37.1 ± 0.4°C for the three conditions, while HR reached 174 ± 29, 183 ± 3, and 179 ± 12 bpm at the end of the exercise. During cooling session just after the exercise, $\bar{T}_{sk}$ dropped by 0.49 ± 0.19 °C and 0.57 ± 0.24 °C for the Unprocessed and Graphene conditions, while for the control $\bar{T}_{sk}$ dropped by 0.03 ± 0.00 °C during the 30-min cooling session (**Table 1**). It took 6.7 min (Unprocessed) and 9.5 min (Graphene) to rise again to the $\bar{T}_{sk}$ level at the end of exercise, which indicates that (1) the cooling power of the Graphene sheet lasted on average 2.8 min longer than that of the unprocessed sheet even though the difference was not significant, and (2) the unprocessed cooling sheet should be replaced at least every 6 ~ 7 min with a newly water-soaked sheet. Also, there were no significant differences in HR or total sweat rate among the three conditions. Concerning thermal sensation, subjects felt “cool” to “cold” when being covered by the cooling sheets, showing significant differences with the control condition ($P < 0.05$), but there were no statistical differences among the three conditions as the cooling time passed. No differences in TC and SS among the three conditions were found. In addition, most subjects felt stuffy after just 10 min of being covered by the cooling sheet. Taken together, cooling the body using water-soaked sheets could be effective to reduce high skin temperature and to improve thermal sensation, but the effects last about 6 ~ 7 min. Furthermore, graphene-oxide coated sheet lowered $\bar{T}_{sk}$ more than the unprocessed sheet.

Table1. Mean skin temperature (̄,*T*sk) for the three experimental conditions (unit: °C).

Phase	Control	Unprocessed cooling	Graphene cooling	P-value (a<b<c)
Rest	34.1 ± 0.5	34.3 ± 0.3	34.2 ± 0.3	N.A
Exercise (last 3 min)	36.8 ± 0.5	36.8 ± 0.5	36.6 ± 0.5	N.A
Pre-cooling supine position (last 3 min)	36.9 ± 0.3	37.2 ± 0.4	37.1 ± 0.3	N.A
Minimum $\bar{T}_{sk}$ during cooling session	36.5 ± 0.0^{b}	36.5 ± 0.0^{c}	36.4 ± 0.0^{a}	< 0.001
Δ ̄,T_{sk} (Pre - Minimum $\bar{T}_{sk}$ during cooling session)	0.03 ± 0.0^{a}	0.49 ± 0.19^{b}	0.57 ± 0.24^{b}	< 0.001
End of the cooling session (29~30th min)	36.4 ± 0.4 ^{a}	36.9 ± 0.3 ^{b}	36.3 ± 0.4 ^{a}	< 0.05

Conclusions

We found cooling benefits of the graphene oxide-coated sheet to reduce skin temperature for the exertional hyperthermic subjects when compared to the original unprocessed sheet. Even though the difference was not that notable, the cooling power lasted about 3-min longer for the graphene condition. In addition, the present results suggested that the unprocessed cooling sheet should be replaced at least every 6~7-min with a newly-soaked cooling sheet. Because this study was conducted with only 6 males as a pilot test, further studies with more subjects and various experimental conditions (e.g., ice packs or fans added to the cooling sheet, various concentrations of graphene oxide coating, etc.) are required.

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The influence of cellulosic content on heat dissipation in knits

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Keywords
cellulosic fibres, thermal effusivity, heat dissipation, test method, handfeel, hydrophilic fibres, hydrophobic fibres

Introduction

The perceived cool and warm perception of textiles is an important aspect of physiological comfort. A textile surface, that quickly dissipates heat, is perceived as cool and would be considered pleasant under normal conditions. A smooth surface is usually perceived cooler. This property, expressed as thermal effusivity, depends mainly on the thermal conductivity, the density and the heat capacity of the surface material, and can be influenced by the available contact points between the hand and the surface. Due to the moisture absorbed inside the fibre, cellulosic fibres show a higher thermal capacity than non-absorbing fibres and fabrics made thereof would usually feel cooler at first contact than comparable fabrics made of synthetics (1). This transient thermal feeling can be assessed objectively by the thermal module of the Kawabata KES-f system as Q_{max} [J·s/cm²] as the maximal amount of heat flow through the fabric in 100 seconds (2), or by later developments like Alambeta and C-Therm, which defined the term "*thermal absorptivity*" (later called *thermal effusivity*) as the ability of the material to exchange heat with its surroundings (3, 4, 5).

$$e = \sqrt{\lambda * \rho * c_p}$$

Whereas λ is the thermal conductivity in W/mK, ρ the density in [kg/m³] and cp the heat capacity in J/kgK. The unit for thermal effusivity is hence [W $s^{1/2}$ / m^2 K].

This work presents the role of cellulosic content in heat dissipation of a lyocell/polyester blending gradient in single jersey fabrics, as measured by a new device. The *Thermal Effusivity Tester* (TET) is developed at Lenzing AG (Austria) to measure thermal effusivity and conductivity of textiles under defined contact pressure.

Methods

Two series of single jersey fabrics, with 5% and without Elastane (EL), were knitted from Ne 30 ring yarns of polyester (PES), lyocell (CLY) and their 50:50 and 85:15 blends, to approx. 120 g/m² for the Elastane-free and 170 for the Elastane-containing fabrics (Table 1.), at a SCC548 Terrot circular knitting machine with 30" diameter, E28 Gauge.

To measure heat dissipation and conductivity with the *Thermal Effusivity Tester*, the fabric is placed between two plates, of which each is kept at constant temperatures. The lower plate is fixed, the, warmer, upper is mobile. As soon as the heat equilibrium between the fabric and the lower plate is detected, the upper plate moves downwards until the fabric surface is compressed according to a pre-set penetration tolerance (in these measurement 10%) of the given fabric thickness. The heat flow through both plates is recorded. At the time the upper plate begins to contact the test specimen, heat is flowing into the material. The amount of heat flowing into the fabric is determined by the heat difference between the two sensors. The equilibrium of heat flow in and out of the fabric is reached. The maximal heating of the specimen is recognized by the conversion of the heat flow of both sensors. The thermal conductiviy is determined from this steady-state heat flow (*q*) and the temperature gradient, following the Fourier conduction equation

$$q = \lambda . \frac{A}{L} . \Delta T$$

Whereas *λ* is the thermal conductivity, *A* the cross-sectional area, *L* the fabric thickness, and *T* the temperature. Thermal effusivity is obtained from the thermal conductivity, the specific heat capacity and the fabric density as shown above. The specific heat capacity is obtained from total heat absorbed by the material during the test, the average temperature rise and the fabric density.

Results and discussion

As shown in Figure 1, the thermal effusivity of the fabric is significantly influenced by the content of cellulosic material in the fabric. Even in minority blend, cellulosic fibre improves heat dissipation. Furthermore, adding Elastane to the fabric seems to significantly enhance the heat dissipation in the fabric, most probably due to increasing the contact points on the surface in the fabric compacted by the Elastane. While thermal conductivity (Table 1) in the thinner Elastane-free fabrics is also influenced by the cellulosic content, it remains almost the same in the compacted Elastane-containing fabric, with a slight drop of conductivity in the 100%

polyester fabric, lacking the moisture absorbing content. The results of the compacted fabrics also show that thermal effusivity is independent of thermal conductivity.

Table 1. Single jersey fabric constructions and the measured thermal conductivity and effusivity.

Fibre blend			Fabric weight	Fabric thickness	Conductivity	Effusivity
CLY	**PES**	**Ealstane**	**[g/m²]**	**[μm]**	**[W/mK]**	**[W s1/2 /m² K]**
100	0	No	131	0.55	0.090	142
50	50		134	0.55	0.087	116
15	85		124	0.48	0.072	71
0	100		120	0.45	0.070	63
100	0	Yes	174	0.67	0.099	184
50	50		179	0.68	0.099	160
15	85		185	0.67	0.100	143
0	100		177	0.57	0.093	139

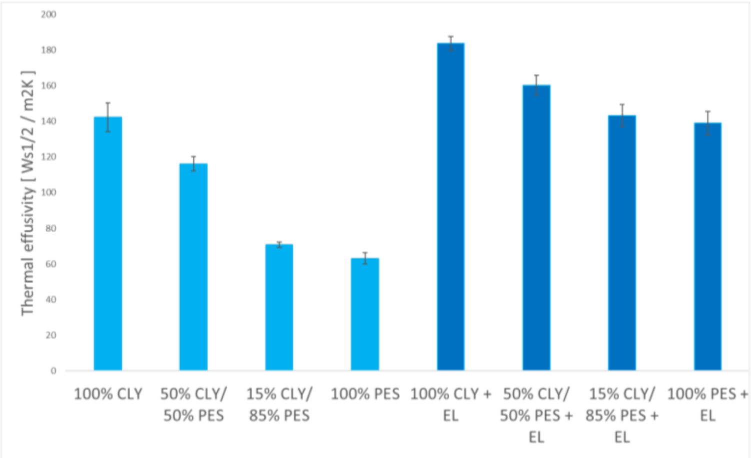

Figure 1. Thermal effusivity on single jersey fabrics made of different blends of lyocell (CLY) and polyester (PES) fibres, with and without Elastane (EL).

Conclusions

Thermal effusivity on single jersey fabrics were measured by a new device. The results show that cellulosic content can improve cool feeling in the fabric even in minority blends due to the moisture contained inside the fibres. Compacting the surface by adding Elastane leads to higher heat dissipation due to the increasing of the number of contact points with the surface.

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Development of digital garment clothing pressure distribution using 3D vector projection

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Keywords
3D digital garment, clothing pressure distribution, real clothing pressure, 3D vector projection

Introduction
Clothing pressure has many applications, including medical compression suits, sportswear base layers, and protective clothing innerwear. It plays an important role in comfort and acts as a direct variable to the body's physiological, kinetic, and heat transfer mechanism. Recently, 3D digital clothing has been gaining popularity as a core technology in various fields, including clothing, design, and marketing. However, the digital garment pressure distribution provided by these virtual try-on programs shows results far from actual pressure. At a time of increasing interest in the practical implementation of digital clothing, an accurate implementation of digital clothing pressure is needed for a safe and pleasant clothing environment and functional clothing design. This inquiry can provide beneficial data for the industry as a whole and for related fields of academia. The study aims to develop a program that realistically implements digital clothing pressure distribution using 3D vector data.

Methods
MATLAB program was used to calculate the strain of the garment mesh and the distance from the avatar. It was then programmed to calculate the output of the garment pressure distribution as a 3D graph. Through use of the 3D CLO (CLO 3D, South Korea) program, avatars (AVs), flat 3D shapes (FGs) with close-fitting clothing patterns, and 3D shapes (VGs) attached to the avatar were acquired as OBJ files and used as input values. The strain of the mesh transformed into 3D in the flat state and the distance between the avatar and the costume were measured by the vertex coordinate distance by measuring the Euclidean distance equation. In addition, the internal forces of the garment were calculated to reflect its material characteristics, and the forces were 3D vector-projected in the direction of the body to reflect the curvature information of the wearer's body shape. On the basis of the vertex, the strain of each adjacent facet was multiplied by Young's Modulus, fabric thickness, and faces to obtain the internal force of the garment. Then it was vector-projected in the direction of the body and divided by the charge area to calculate the 3D digital garment pressure value. The pressure results analyzed in this way were color-mapped and printed out as a 3D graph so that they could be easily identified to confirm distribution. To verify the actual clothing and pressure values, the real try-on was manufactured, and the pressure was measured as shown in Figure 1 (AMI-3037, AMI Techno, Co., Ltd, Japan).

Table 3. Physical properties of materials.

		Young's Modulus_Course (MPa)	Young's Modulus_Wale (MPa)	Thickness (mm)
Fabric A		1.97562	6.2224	0.30
Fabric B		1.39964	1.31295	0.57

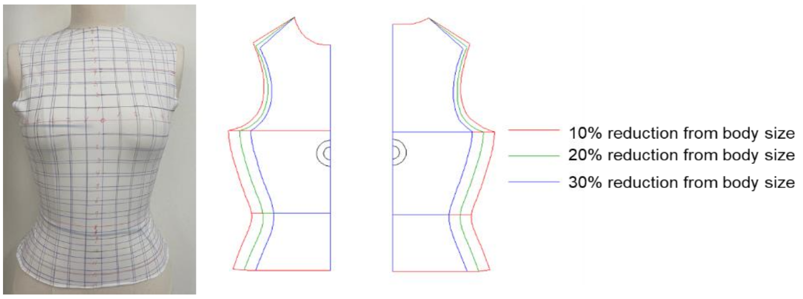

Figure 1. Real clothes image and patterns.

After 3D digital try-on was implemented under the same conditions, the program developed in this study was tested. A comparison of the digital try-on pressure distribution showed in Figure 2 and the error rate was about 5%.

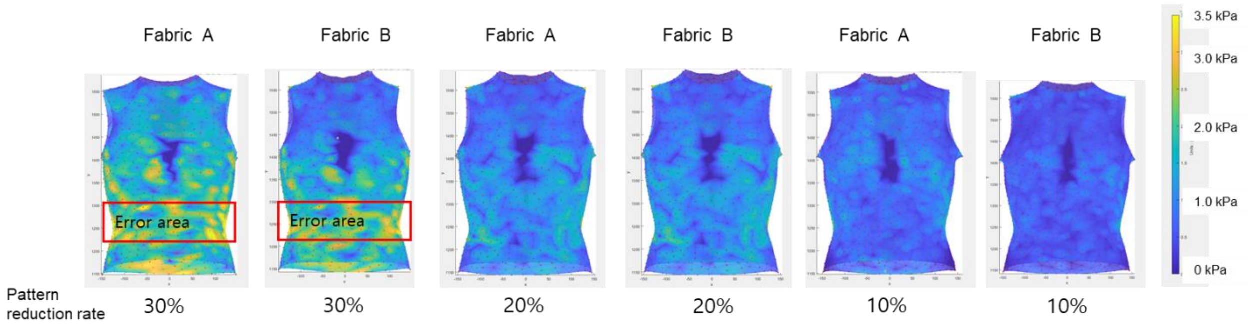

Figure 2. Comparison of real try-on and digital try-on pressure measurement.

Conclusion

The program developed in this study successfully predicted the pressure of digital clothing. This can contribute to increased economic efficiency in various functional clothing industries, such as protective clothing, medical clothing, and sportswear, by omitting the process of actual abdominal pressure measurement and providing realistic clothing pressure via digital simulation.

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Exploring holistic body mapping and its application in a foul weather garment

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Keywords
body mapping, sweat mapping, wetness sensitivity mapping, temperature sensitivity mapping, body-mapped clothing, foul weather garment

Introduction
Body maps show the distribution of thermoregulatory processes or sensitivity to stimuli across the human body. Though there are many different body maps, they have not yet been combined to cover sweat rate, wetness perception, and temperature sensitivity in a single, holistic body map. By mapping the required textile properties to their designated body parts, thermal management of a garment could be improved (1). Using holistic body mapping could further increase this benefit of body mapping. The implementation of body maps in garment design is often left to designers. This research is an example of how clothing designers might interpret and combine different body maps and how they would implement them in the development of body-mapped garments. The garment at hand is a foul weather garment worn during light exercise with the goal of reducing wetness perception and uncomfortable temperature sensation.

Methods
Sweat maps, wetness sensitivity maps, and temperature sensitivity maps by researchers in Table 1 were reviewed, combined, and summarized per type of map. Overlaying the summarized sweat maps, wetness sensitivity maps, and temperature sensitivity maps resulted in an unreadable body map. For that reason, further processing of information was required to make a holistic body map a useful tool to implement in clothing design. Highlighted areas of the sweat maps were combined with the highlighted areas of the wetness sensitivity maps to show areas in which both wetness sensitivity and perspiration are high, therefore highlighting areas that have the highest chance of wetness perception. Temperature sensitivity maps were grouped in cold and warm sensitivity, and their derivatives were then combined to determine where on the body both warmth and cold sensation were high. Next to moisture management and temperature sensitivity, cold impact was also implemented to account for the different temperatures of air the body is exposed to, which is not considered in body map development.

Table 1. The reviewed body maps.

Sweat mapping	Wetness sensitivity mapping	Temperature sensitivity mapping
Smith and Havenith 2011 (2), Smith and Havenith 2012 (3)	Valenza et al. 2019 (4), Filingeri et al. 2014 (5), Park and Yoo 2011 (6)	Filingeri et al. 2014 (5), Ouzzahra et al. 2012 (7), Luo et al. 2020 (8), Gerret et al. 2014 (9), Schmidt et al. 2020 (10), Valenza et al. 2019 (4)

Results
Combining the maps as described above results in the body map in Figure 1. The interpretation that results from this body map depends on the desired body-mapped garment. For the foul weather garment at hand, body mapping was done in two steps: ventilation mapping and insulation mapping. The moisture management map (green) was prioritized due to the importance of sweat evaporation in heat loss during exercise and the desire to reduce wetness perception. Areas with a high chance for wetness perception were addressed by implementing ventilation features in the garment at those areas. Considering the areas of the moisture management map now have an inlet of cold air, the respective areas are exposed to more cold than the areas in which no ventilation features are present. Therefore, insulation mapping was done considering this additional inlet of cold air. In insulation mapping lining fabrics with differing thermal resistances were used (Figure 2). Further testing is required to confirm the effect of holistic body mapping in the foul weather garment.

Discussion
The comparison and combination of different body maps is complicated by the use of differing test subjects, environmental conditions, and exercise specifics in body map development. Furthermore, several steps of simplification are required in body map combination to create a map that is useful for garment design. Leaving up body map simplification, combination, and implementation to the designer could therefore result in errors in each of these steps. In applying body maps, prioritization depends highly on the garment at hand. Additionally, the effect of body mapped features on the body maps themselves should be considered as well. As seen in the foul weather garment, ventilation features to address the moisture management map influence the way in

which the temperature sensitivity maps should be considered. The other way around, mapping fabrics with different insulative properties to address temperature sensitivity distribution could result in differing skin temperatures and therefore affect local sweat rates.

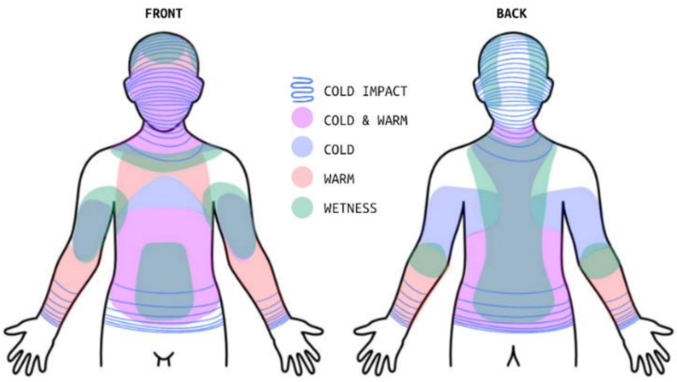

Figure 1. The developed body map.

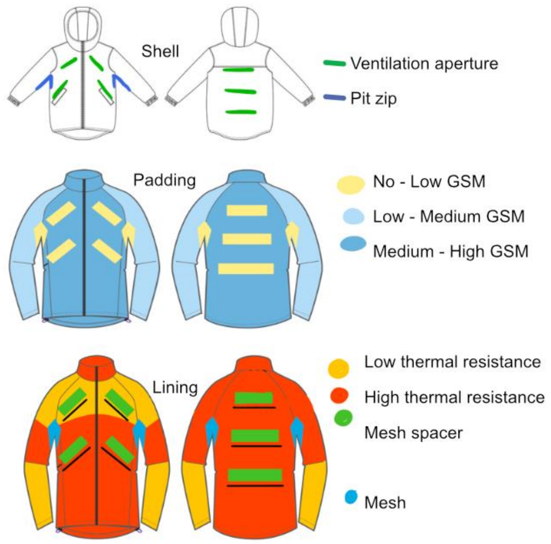

Figure 2. The developed garment per layer.

Conclusions

Body map simplification, combination, and implementation are complicated processes due to the differences in body map development, the interplay of factors, and the required custom approach for each type of garment. For a foul weather garment worn during exercise, holistic body mapping was applied by addressing wetness sensation through the implementation of ventilation features, and using insulation mapping to reduce uncomfortable temperature sensation. This research invites the further investigation on how body maps can be best combined and interpreted for the design of thermally comfortable garments.

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Evaluation of health tracker's functionality in terms of its potential application to control the operation of protective clothing with cooling function

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Keywords
health tracker, cooling clothing, smart clothing, functionality, wearables, IoT

Introduction
Working in a hot microclimate is associated with many negative aspects, such as overheating, reduced work efficiency, difficulty in concentrating and reduced ability to perform physical work [1-4]. Workers in the construction sector are particularly exposed to the influence of a hot microclimate at work. One way to reduce the effects of working in a hot microclimate and reduce workers' thermal discomfort is to use protective clothing with a cooling function. As thermal sensations may vary among workers, it is important to ensure the possibility of adjustment of the cooling intensity to the individual needs of the user. One of the parameters that proves the body's attempt to fight overheating is the increased value of the heart rate associated with the dilation of blood vessels. The EN ISO 9886:2004 standard [5] indicates the limit values of the heart rate that prove the thermal load of a person. Smartwatches are popularly used health trackers to monitor the heart rate, which can be cheap and widely available equipment. Therefore, the assessment of possibility of using a smartwatch to control the operation of protective clothing with a cooling function based on the measurements of the heart rate value in almost real-time was the aim of the experiment. In order to increase occupational safety of the construction workers, in ASSIST-IoT project we assumed that real-time heart rate monitoring will allow cooling to be adjusted before the heart rate reaches its limits, thereby reducing the thermal stress of those exposed to hot microclimates during work.

Methods
In order to evaluate health trackers' functionality in terms of their application to control cooling intensity, utility tests were carried out using the selected cheap of-the-shelf PineTime smartwatch and, as a reference, the Equivital system for measuring physiological parameters. The PineTime smartwatch was selected for its relatively low cost, the ability to use custom software, long battery life, dust and water resistance, vibration and a color display for worker communication. The tests were carried out with the participation of 6 people (3 men and 3 women) under controlled environmental conditions in the SMART PPE TESTLAB Research and Demonstration Laboratory in the CIOP-PIB. Laboratory tests were carried out at an ambient temperature of 25 °C and a relative humidity of 65%. The average age of the participants was 32.2 ± 6.1 years, the average height was (174.5 ± 11.0) cm, and the average weight was (67.4 ± 11.7) kg. During the study, participants performed a series of physical activities that included walking on a treadmill at 5 km/h and 3 km/h, as well as exercises using upper lift. During the tests, special attention was paid to evaluation of the impact of hand movement on the correct indications of the smartwatch. Obtained results from the smartwatch and professional equipment for heart rate monitoring were compared and evaluated.

Results
Laboratory tests of heart rate measurements using the PineTime smartwatch have shown that the reliability of this hardware is questionable when compared to the results obtained with equipment designed to measure physiological parameters. The collected data from the wristband is unstable and there are sudden and uncontrollable changes in its values (Figure 1). The most significant differences reaching even 20 bpm have occurred during increased velocity of marching, while in the case of lack of activity (breaks) or slower body movements (march with 3 km/h or exercised with upper lift), the obtained differences were about 5 bpm. Obtained results indicate also that in most cases, heart rate values measured by means of Equivital system were on a higher level than in the case of measurements conducted with a use of the smartwatch.

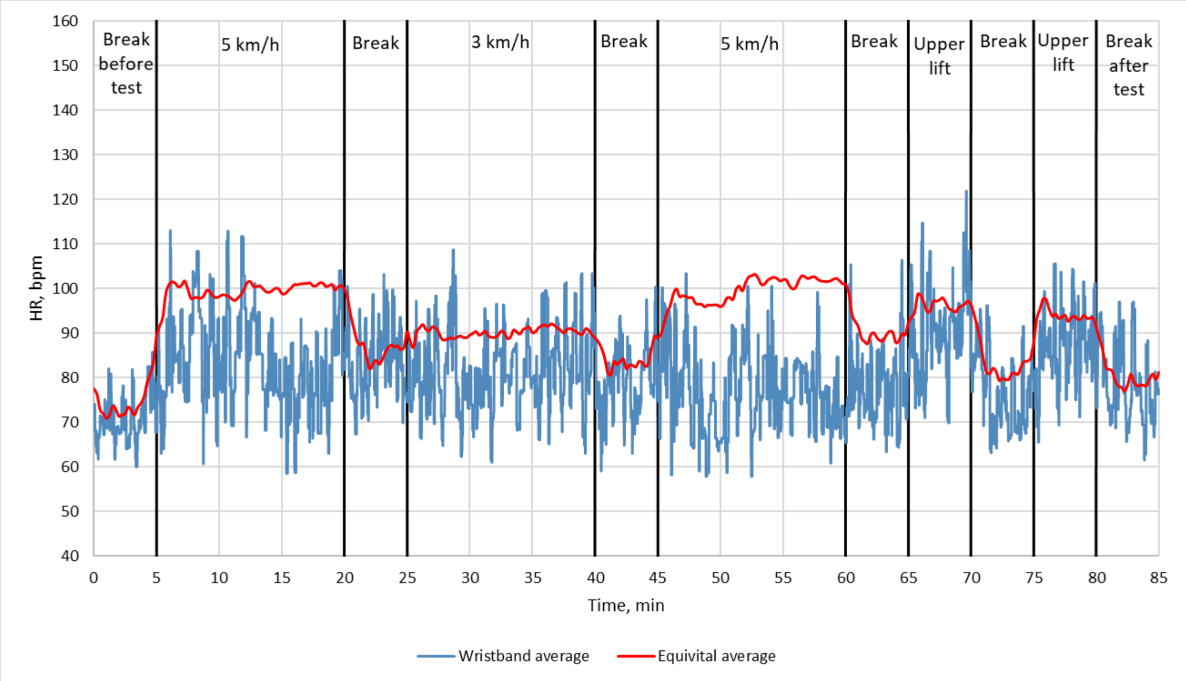

Figure 1. Graph of changes in heart rate during the test – average values.

Discussion and Conclusions

The conducted research indicates that the use of a cheap of-the-shelf heart rate monitoring smartwatch to control the operation of protective clothing with a cooling function is possible, however, the integration of algorithms that can perform necessary corrections is needed. Moreover, the algorithms need to distinguish dynamics of exercised performed, in order to ensure that during higher-speed activities, when particular risk to health exists, the measured heart rate values are not underestimated. In addition, compensation of heart rate peaks resulting from, e.g., sudden movements of the hand should be provided. To sum up, the potential for the use of a cheap of-the-shelf smartwatch as a cooling control device is high due to the ability of quick detection of heart rate limits that indicate thermal stress. The use of cheap and widely available smartwatches will make it affordable for a large group of industrial companies, which could benefit in increased safety of workers from such a solution. However, without implementing additional algorithms, the reliability of such solution is limited. In the ASSIST-IoT project, additional control measures based on adaptive filtering techniques will be introduced to overcome this issue. The filtering algorithm will be implemented on the smartwatch, which presents a challenge due to the device's very limited computing capabilities. It should be taken into account that other psychological factors, such as stress or physical activity can also affect the heart rate. Therefore, the control of the cooling function should be supported by additional data, e.g. temperature measurement in the undergarment microclimate.

Acknowledgments

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Assessment of fire investigator ensembles against chemical vapor and airborne particle infiltration

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Keywords
fire investigator, firefighter, fireground contaminants, chemical protection

Introduction

The evolution of Personal Protective Equipment (PPE) used in the fire service has historically focused on the thermal protection and thermal burden of firefighters. While these advancements in firefighter PPE have been impactful, the notion of protecting firefighters has now grown to include protection from fireground contaminants. These fireground contaminants have been found to contain harmful and carcinogenic compounds including Volatile Organic Compounds (VOCs), Polycyclic Aromatic Hydrocarbons (PAHs), and Polychlorinated Biphenyls (PCBs). (1) It is currently believed that these contaminants are the cause of the elevated rates of cancer in the fire service. (2) While firefighter PPE and procedure has grown to mitigate these hazards, other occupations in the fire service have not, particularly fire investigators. As these investigators typically operate at extinguished fire scenes for extended periods of time, they are often exposed to a significant amount of fireground contaminants. Despite this knowledge, PPE used for fire investigations is rarely standardized. This has created the need for suitable and effective PPE selections for fire investigators working at the fire scene.

Methods

To determine the effectiveness of fire investigator PPE, a selection of ensembles was tested against chemical vapor and aerosolized particulate. Chemical vapor testing was conducted in accordance with the National Fire Protection Association's (NFPA) Man-In-Simulant Test (MIST) protocol for determining the protection factor of a complete ensemble against the infiltration of chemical vapor. (3) This test utilized live subjects donned with the selected ensembles to perform exercises within a controlled environmental chamber to detect infiltration of chemical vapor into the ensemble via Passive Adsorbent Dosimeters (PADs). The anatomical location and placement of these PADs can be seen in Figure 1 below. (3) Aerosolized particulate testing was carried out utilizing a prototype manikin with integrated real time aerosol detection to determine the localized infiltration of airborne particulate into the ensemble. This was carried out using five separate particle counting sensors integrated into the chest, arms, and thighs of the manikin.

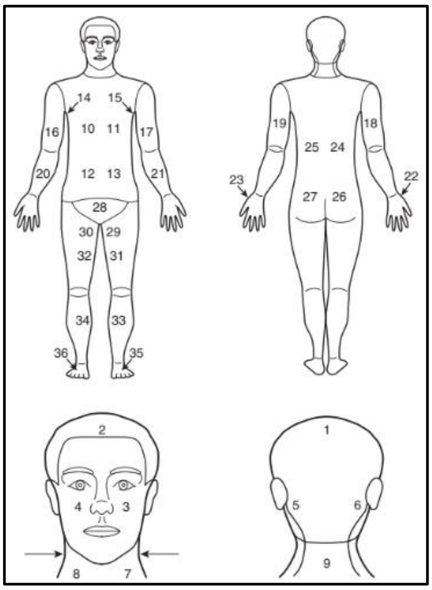

Figure 7. MIST PAD Locations (3).

The selection of ensembles used in testing included representative PPE commonly used by fire investigators as well as prototype garments selected for their suitability for use in fire investigations (Table 1). These 10 ensembles included the following: a base layer long sleeve shirt and tactical pant to be tested alone and worn in conjunction with the 10 other ensembles, 2 differing types of disposable coverall, 2-piece and coverall ensembles constructed with a single-layer turnout material, a prototype 2-piece ensemble with particulate blocking fabric, a traditional 2-piece structural turnout ensemble, a 2-piece and coverall particulate blocking structural turnout ensemble, and a military surplus flight suit with a carbon impregnated sportive layer. In addition to the base layer, all ensembles included socks, undergarments, nitrile gloves, and a full-face Air Purifying Respirator (APR). All ensembles were combined with boots, outer gloves, and helmets that differed for the 8 non-structural and 3 structural ensembles. This permitted the 3 structural turnouts to be worn as intended for response to active fires and freshly extinguished fire scenes.

Table 1. Ensemble Selection.

	Ensemble		
	Class	Type	Style
1	Base Layer		
2	Model 400	Disposable	Coverall
3	Model 800	Disposable	Coverall
4	Flight Suit		Coverall
5	Rescue/Wildland	Single-Layer	Coverall
6	Rescue/Wildland	Single-Layer	2-Piece
7	Rescue/Wildland	Particulate-Blocking	2-Piece
8	Structural Firefighting	Traditional	2-Piece
9	Structural Firefighting	Particulate-Blocking	2-Piece
10	Structural Firefighting	Particulate-Blocking	Coverall

Results and Discussion

Initial chemical vapor testing has indicated that base layer protection was minimal, followed closely by disposable coveralls and single-layer turnout ensemble performance. Structural turnouts (2-piece and coverall), 2-piece particulate coveralls, and flight suit ensembles performed significantly better. Results were calculated from PAD absorption data in the form of 36 localized protection factors and a single systemic protection factor for each ensemble. Four separate rounds of testing will be concluded to give average protection factors indicating capabilities and limitations for each ensemble. The remaining chemical vapor testing will be carried out in January and February of 2023 and the subsequent results will be used to ensure adequate replication needed for considerable conclusions.

Aerosol particulate testing is currently ongoing as of of 16 April 2023. Results for particulate testing will be reported sinilarly to MIST testing with 5 localized protection factors and a singular systemic protection factor for each ensemble for each round or testing. Laastly, all final results will be collected and processed into a final report and poster for dissemination to the public.

Conclusion

Fire investigators will always need to interact with fireground contaminants, however, reducing direct exposure to these contaminants should be prioritized. By informing and educating fire investigators on how various ensembles perform, this study seeks to help investigators and departments make more informed decisions regarding appropriate PPE to be worn to investigatory fire scenes. Likewise, PPE manufacturers and industry professionals would benefit from understanding the needs of fire investigators for suitable and effective PPE for protection from fireground contaminants.

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Preliminary research to determine effectiveness of on-scene hose decontamination through comparison of different analysis techniques

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Keywords
firefighter, firehose, care, cleaning, decontamination

Introduction

Firefighters are exposed to numerous carcinogenic agents in their everyday work environment. (1) One of the ways that they can be exposed to these chemicals is through direct skin contact with fire hoses. The hoses get dragged throughout the scene of a fire and can pick up harmful toxins that could be transferred to the firefighters. Current decontamination procedures include brushing a dry hose with a hard bristle brush. (2) Transporting and drying the hose at the firestation provides the opportunity for cross contamination and exposure to dangerous chemicals picked up at the fire scene. On scene decontamination could provide a solution to this problem. To test the effectiveness of on scene decontamination, colorimetric and chemical analysis have been used to quantify the removal of particulates that could carry the carcinogenic agents. The most common method for previous analysis has been chemical identification using instruments such as the gas or liquid chromatography. Colorimetric data could provide a less expensive method for gathering data that would be more accessible for smaller laboratories. The purpose of this analysis is to explore options for hose decontamination methods using different combinations of water, soap, scrubbing bristles, while simultaneously comparing chemical analysis with colorimetric analysis techniques to quantify decontamination.

Methodology

Two separate controlled fire simulations were created to contaminate the fire hoses and balance realistic aspects with replicability to be as real-world applicable as possible. The first simulation accounted for the replicability factor. Hose 1 and hose 2 were given to Central Carolina Community College Fire Department to be used as the primary attack nozzle during fire training exercises. The burn took place in a concrete structure packed with straw and wood pallets. The structure was designed for training and contained soot from previous training not associated with this experiment. Fire hose 1 was exposed 16 times and washed at the end of each of the 9 training sessions. Fire hose 2 was exposed 16 times and was never subject to on scene decontamination. The second simulation followed a more realistic aspect. Hose 3 and hose 4 were given to the Carrboro Fire Department to be used as the first 100 feet of fire hose entering the building. The building was a retired house built in the 1960's that was donated to the fire department to be used for training exercises. The first few days of training consisted of wood and hay burning in singled out rooms. The last day involved burning different furniture, and then burning the house to the ground. Fire hose 3 was exposed 20 times and was washed at the end of each of the 5 days. Fire hose 4 was exposed 20 times and was never subject to on scene decontamination. Small sections of the fire hoses were cut and analyzed with either colorimetric or chemical analysis techniques.

Results

For the colorimetric analysis, the level of particulates decreased with a water-based decontamination method for both hose trials. The Central Carolina Community College hoses showed an average particulate percent decrease of 61.7 %. The Carrboro fire hoses showed an average particulate percent decrease of 84.8 %.

For the chemical analysis the decontaminated hoses had less fluoranthene and pyrene than the contaminated hoses. There was an average of a 22.77 % decrease in fluoranthene between the contaminated hoses and the decontaminated hoses. There was an average of a 33.17 % decrease in pyrene between the contaminated hoses and the decontaminated hoses.

Discussion

For the colorimetric analysis, water and agitation successfully knocked off contaminants on the hoses, despite the exposure level. The chemical analysis showed successful removal of carcinogenic chemicals from the hoses when subject to on-scene decontamination. Washing the hoses on-scene reduces the amount of particulates and carcinogens that could cause cross contamination at the fire station.

Conclusions

Different ratios of contamination and decontamination have been observed, generally indicating that the more a hose is washed, the less contaminants will be present. This trend was observed with the realistic scenario and the replicable scenario, that allowed for various types of contaminants to be exposed. The colorimetric analysis technique indicated the decrease of particulates when subject to decontamination methods. The chemical analysis provided details of the decrease of carcinogenic toxins present on the hose after decontamination procedures. Together, the colorimetric analysis and the chemical analysis could provide a link between the particulates and the carcinogens that are present on the hoses.

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