SHORT REPORT

ERGO FIREFIGHTER

ASSESSMENT OF COMFORT AND ERGONOMICS OF PROTECTIVE CLOTHING FOR FIREFIGHTERS VS. NORMATIVE REQUIREMENTS IN VARIOUS EUROPEAN COUNTRIES

Project leader:

1. Central Institute for Labour Protection – National Research Institute (CIOP-PIB), Poland

Project partners:

2. Finnish Institute of Occupational Health (FIOH), Finland
3. Instituto Nacional de Seguridad y Salud en el Trabajo (INSST), Spain

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Project leader:

Młynarczyk M.

Authors:

Młynarczyk M.[1], Rissanen S.[2], Jussila K.[2], Kaisto J.[2], Dąbrowska A.[1], Gómez M.[3], Łastowiecka-Moras E.[1]

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2 Aims of the project

The aims of the project were as follows:

- assessment of the subjective perception of thermal comfort and physiological strain of firefighters wearing protective clothing in various European countries (by means of a literature study);
- usability analysis of smart wearable devices to be applied in protective clothing for firefighters in order to improve their safety and comfort;
- analysis of health and safety requirements to be met by protective clothing used by firefighters in various European countries.

3 Methods

The assumed aims of the project have been achieved by:

- a comprehensive literature study regarding the assessment of subjective feelings of thermal comfort of firefighters as well as ergonomics of protective clothing for firefighters
- a comprehensive literature study on the normative requirements for firefighters' clothing in European countries.

The systematic literature study was carried out in selected databases:

- Taylor & Francis
- Science Direct
- PubMed
- Sage Journals
- Springer.

3.1 Criteria for literature study

The databases review was carried out by using selected keywords such as: firefighters, thermal comfort, protective clothing and subjective feelings.

It was agreed that the analysis would cover the articles since the year 2000 (unless the type of exposure would justify older reviews) and that only the articles from European countries would be considered.

4 Results of the literature study

The further part is divided into two parts, the results of:

- literature studies on the subjective perception of thermal comfort and physiological strain of firefighters and
- smart solutions in firefighter's clothing.

4.1 The literature studies on the subjective perception of thermal comfort and physiological strain of firefighters

Short statistic

The topic of firefighters is still valid as proven by the scientific articles published in recent years (Fig. 1).

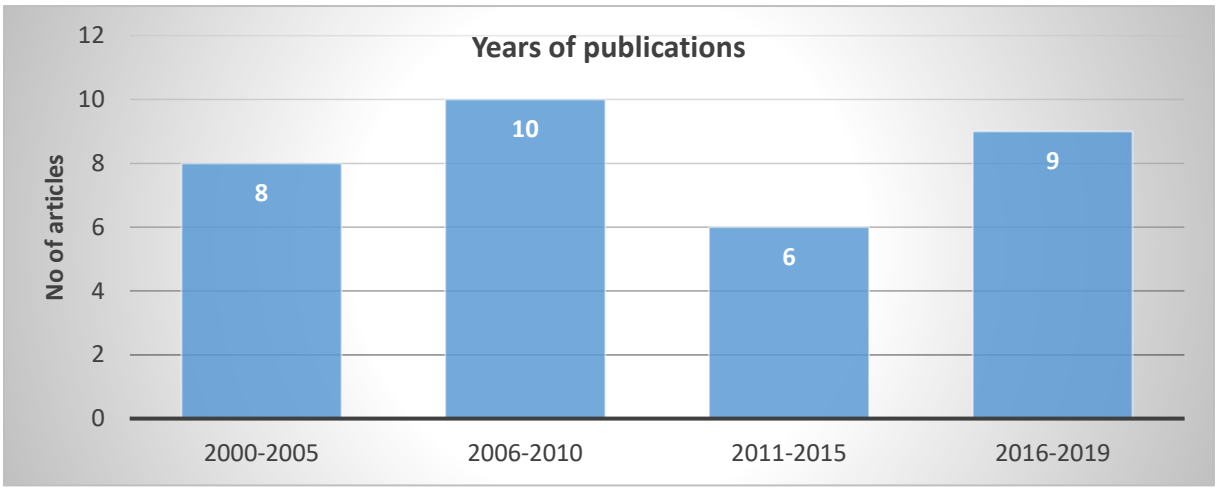


Figure 1 Years of publications

The analysis of the articles showed that the largest number of articles on firefighters' working conditions was published in Finland and in the United Kingdom (Fig. 2).

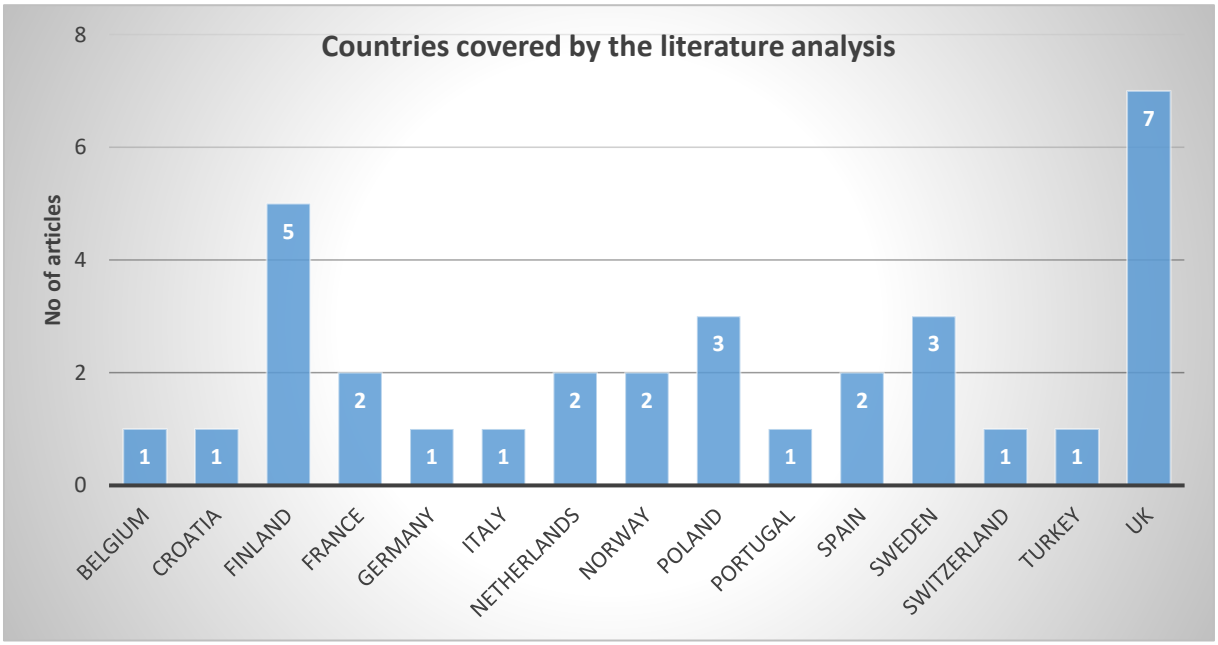


Figure 2 Countries covered by the literature analysis

The research was conducted mainly with the participation of professional firefighters. These were rather small groups of volunteers. In most cases the tested group was composed by less than 10 participants.

In two of the analysed cases, the group consisted of over 100 participants. In the majority of cases the volunteers were professionally active firefighters (95%) (Fig. 3). The remaining 5% were firefighting volunteers or Fire Service Instructors.

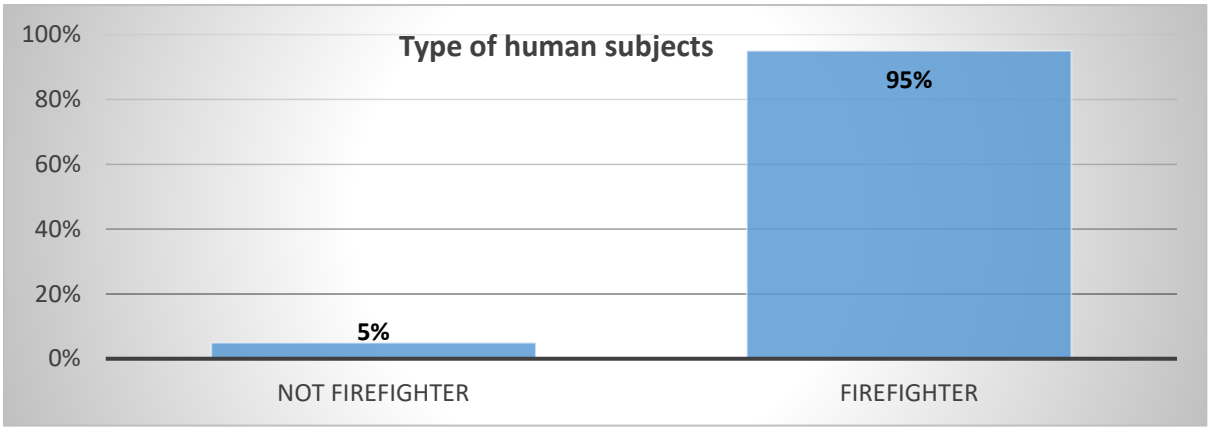


Figure 3 Type of human subjects

In the analysed articles, the most frequently studied and described physiological parameters were heart rate (HR) and respiratory gas exchange (physiological variables of oxygen consumption). HR is an easily measurable determinant of fatigue and body load. The others were: thermal sensation, body weight, sweat production, rectal temperature and mean skin temperature (Fig. 4).

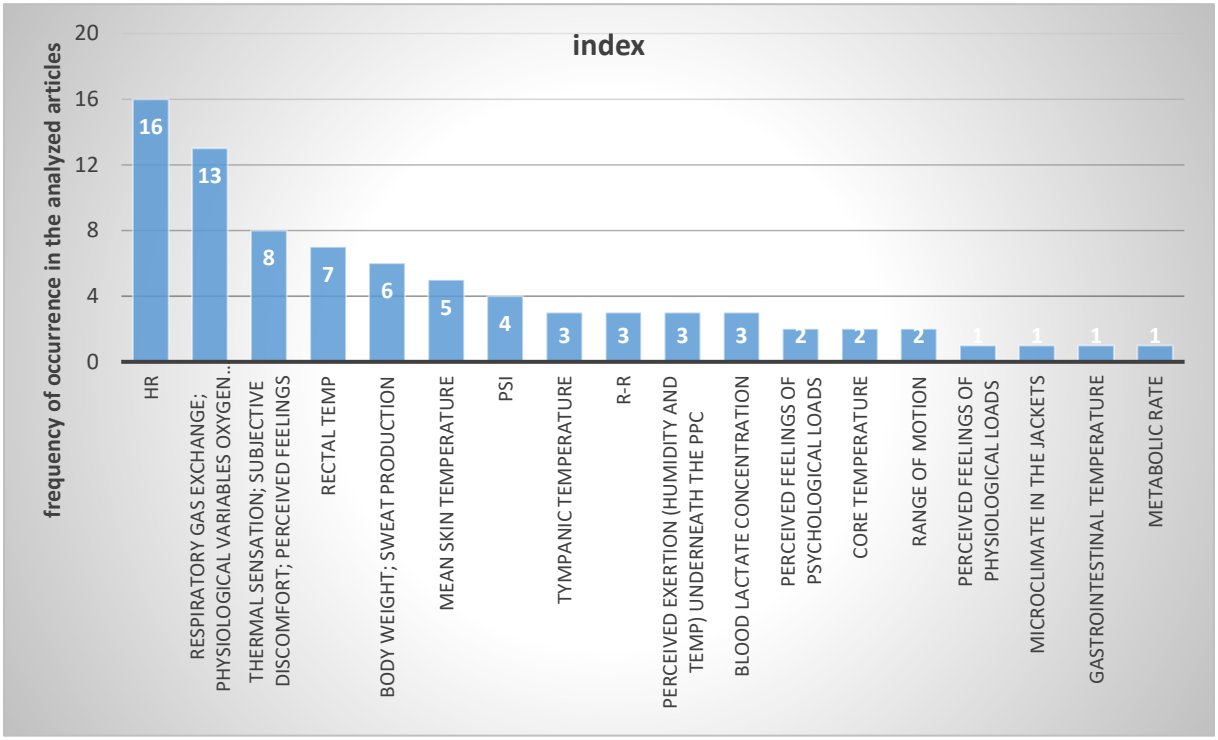


Figure 4 Analysed indexes

Summary and conclusions

Based on the analysis of the 33 articles, it could be concluded that:

- **Occurrence of high thermal stress for human subjects when using protective clothing for firefighters (regardless of the methodologies or test conditions.**
- **The problem of thermal discomfort concerns not only the clothing itself, but also the breathing apparatus or footwear.**

As a result of the analysis the following conclusions can be drawn:

METHODOLOGY

- Research methodology is not uniform; Part of the research was in laboratory conditions (using a treadmill or cycloergometer) and other part of the tests was conducted in controlled conditions simulating the activities performed by firefighters during the service.
  - Used treadmill protocols may not realistically illustrate the strain experienced in real fires.
  - Protocols simulating the activities performed by firefighters such as inter alia: crawling, climbing stairs, advancing a hoseline and pulling down the ceiling, induce responses that more closely replicate live-fire activities
  - Physiological responses obtained during fire simulation tests differ from the results obtained during an aerobic exercise. The physiological parameters were much higher during the fire simulation.
  - Only several studies on physiological responses were carried out during firefighter's regular work shift.

- **Unification of research methodology.**
- **The best solution would be to perform tests under real conditions (unfortunately with a limited number of parameters available).**
- **Protocols simulating the activities performed by firefighters should be used instead of treadmill exercises when studying the physiological strain experienced by the firefighters.**

PHYSIOLOGICAL MEASUREMENTS

- Thermal strain is evaluated by physiological measurements of those parameters and additionally by subjective questionnaires.
  - Limit values of the physiological parameters of thermal strain are set by the ergonomic standard ISO 9886. The most frequently studied and described physiological parameters were heart rate and respiratory gas exchange
  - During regular work shift, mainly the following parameters were examined: heart rate (HR) recordings of R-R intervals, subject's diary of activities and questionnaires of perceived feelings of both physiological and psychological loads (used to assess the experienced strain).

- **The perceptual identification of strain should be incorporated in the normative documents concerning the assessment of thermal strain.**

CLOTHING

- There is a need for changes in clothing for firefighters. The various solutions were examined as improving the work comfort as:
  - ergonomic clothes
  - lighter jackets
  - task-fitted clothes
  - different composition of materials in clothing
- General conclusions about firefighter's clothing:
  - composition of materials in protective clothing affects the sweat efficiency and subjects moisture sensation
  - the range of motion are very important for firefighters
  - weight of clothes (a jacket) correlated in the level of cardiovascular and thermoregulatory stress
  - task-fitted clothes are much better than standard one.

- **The proper underwear is very important. It removes moisture from firefighters' skin, in order to prevent the occurrence of burns and heat stress.**
- **There is a need to introduce changes to the standards with the specific requirements for underwear worn under the firefighter's clothing.**
- **In order to improve the thermal comfort, new and intelligent solutions in clothing can be applied. They could support the thermoregulation system and decrease the heat stress.**

4.2 The literature study - smart solution for firefighter's clothing

Short statistic

The 12 articles were analysed. The topic of new solution in firefighter's clothing is still valid as proven by the scientific articles published in recent years (Fig. 5).

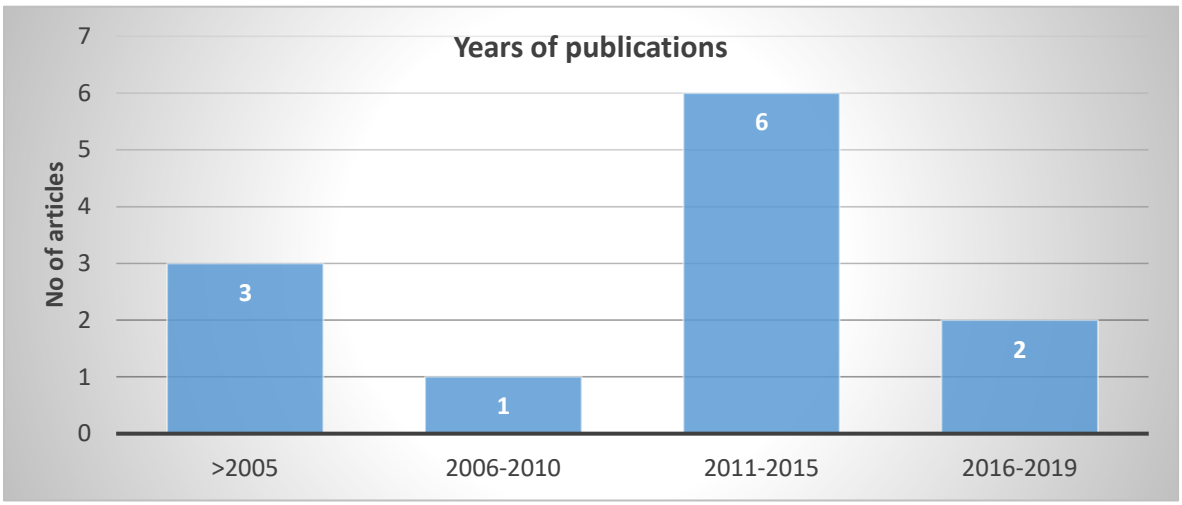


Figure 5 Years of publications

The analysis of the articles showed that the largest number of articles concerning the firefighters' working conditions was published in the UK and Finland (Fig. 6).

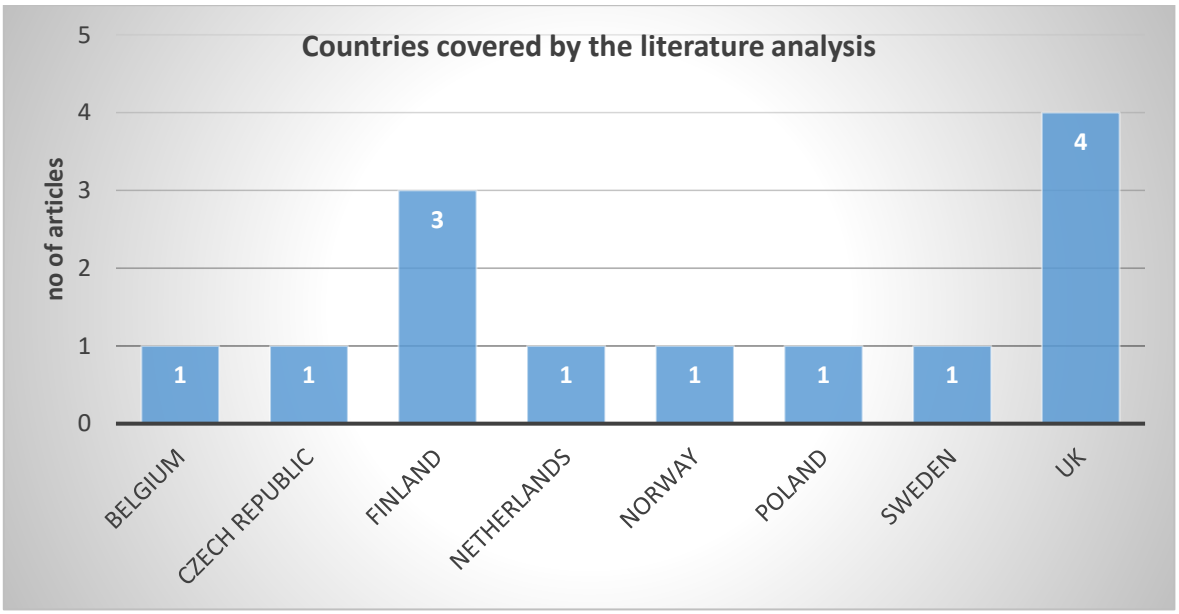


Figure 6 Countries covered by the literature analysis

The research was mainly conducted with the participation of professional firefighters. These were rather small groups of volunteers. In most cases the tested group was composed of fewer than 10 human subjects. In the majority, the volunteers were active firefighters. Excluding surveys, 75% of human subjects were professional firefighters (Fig. 7).

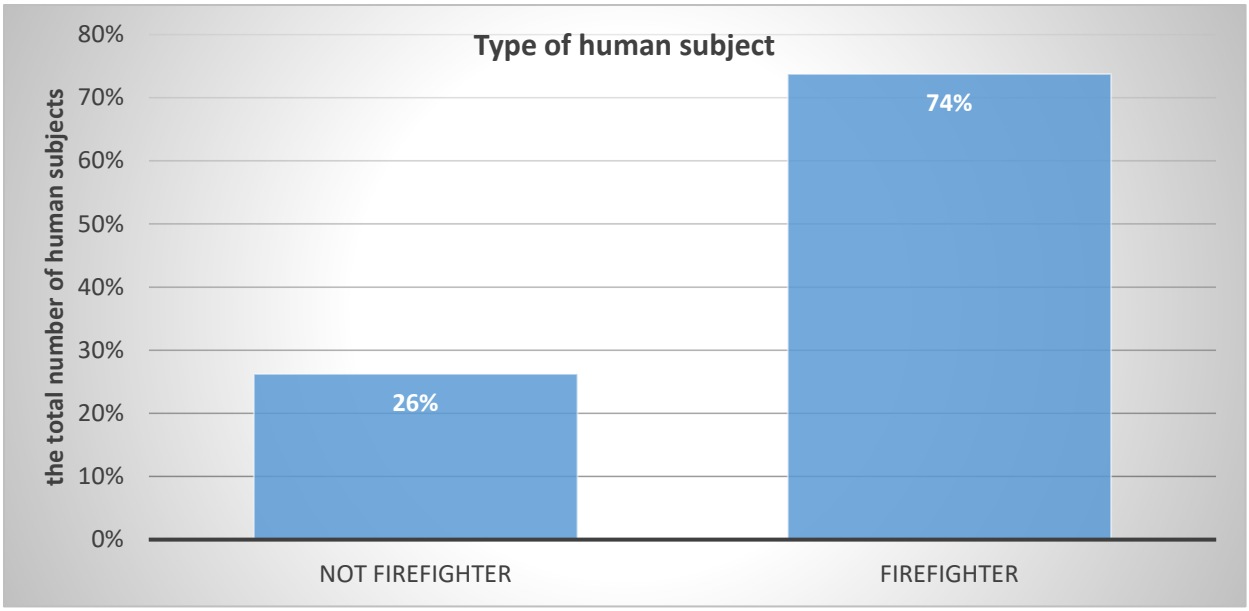


Figure 7 Type of human subjects (without survey)

In the analysed articles, the most frequently studied and described physiological parameters were subjective perception and heart rate. These were followed by: core, skin and rectal temperature as well as sweat production (Fig. 8).

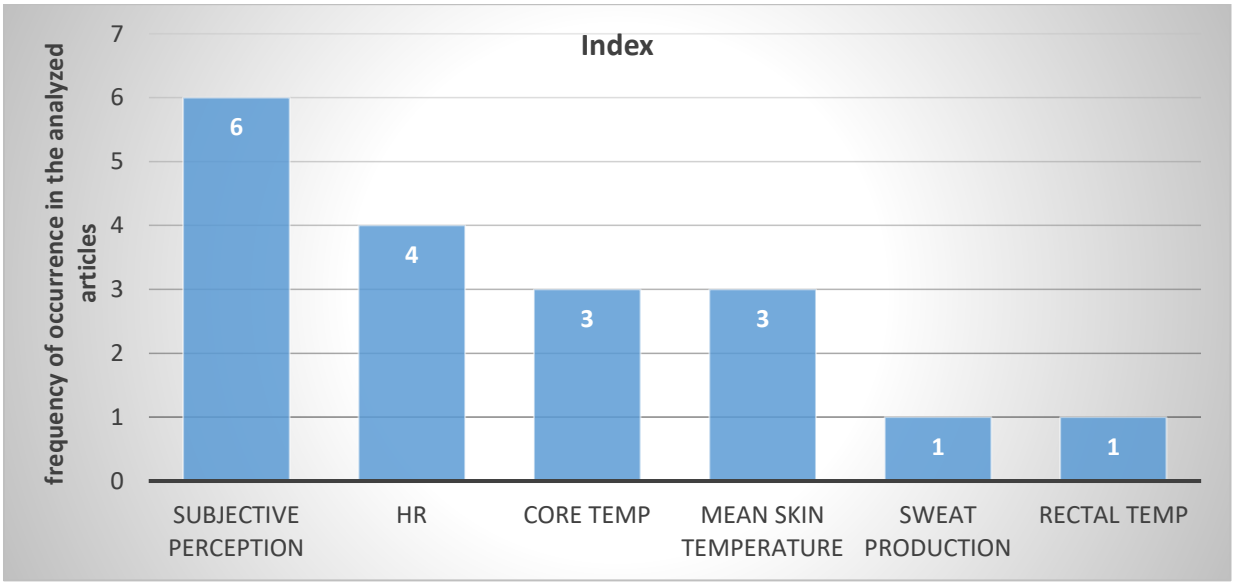


Figure 8 Analysed indexes

Summary and conclusions

There was also analysed the usability of smart solutions to be applied in protective clothing for firefighters in order to improve their safety and comfort.

New solutions for firefighter's clothing were tested mostly in laboratory conditions.

Variety of cooling methods have been developed aiming to reduce the thermal burden:

- ice slurry ingestion before exertion
- immersion methods
- smart textiles (or e-textiles)
    - cooling garments
    - cooling vests (ice, PCM)

Precooling methods is impractical for firefighters, since firefighting is characterized by unexpected and urgent operations. Thus, methods must be able to be deployed either during work or during recovery periods between consecutive work bouts.

Immersion - hands and arms are put in cool water during recovery to enhance reduction of core body temperature through heat exchange between superficial blood vessels and water. Despite the evidence of effective cooling with hand and forearm immersion, it may not be a practical method to reduce the heat strain of firefighters. Setting up the arrangements for cold water immersion at the scenes where firefighters work may be troublesome when taking into account all the characteristics of an emergency incident.

Smart textiles (or e-textiles) are defined as textile products consisting of fibers and filaments that can interact with the user and environment and directly respond to undesirable changes. Such products include thermoregulating garments, in which phase change materials (PCMs) are incorporated into the clothing fibres. PCMs can also be utilized in a form of packs detached for example in a vest. Cooling effect of vest was confirmed. Cooling effects of PCMs incorporated in garment fibres have also been investigated. It has a high but short-lasting cooling effect. The practical use of PCM packs during firefighting is, however, questionable due to their size and weight that may increase the bulkiness of a firefighting suit and the metabolic load of a firefighter.

Wearable electronics: integration of sensors and technologies into garments enable to monitor the firefighter and his immediate environment during work. Fabrics can directly adjust clothing properties according to the wearer's need (for example thermoregulating garments). For instance, heart rate monitors, activity and GPS trackers and temperature and humidity sensors, that are incorporated into clothing fibres or worn as accessories, can be defined as wearable electronics. Measured data can also be transferred through specially designed network to an operation supervisor, who can react for example by pulling off the firefighter from the scene if any of the measured parameters reaches its preset limit values. The hazardous working environment brings challenges for the development of smart protective clothes for firefighters. The electronics must be shielded from heat, moisture and mechanical stress, and they must be integrated so that the wearer is not disturbed by them. Modern sensors and electronics is flexible, light, more durable and batteries are well developed and light.

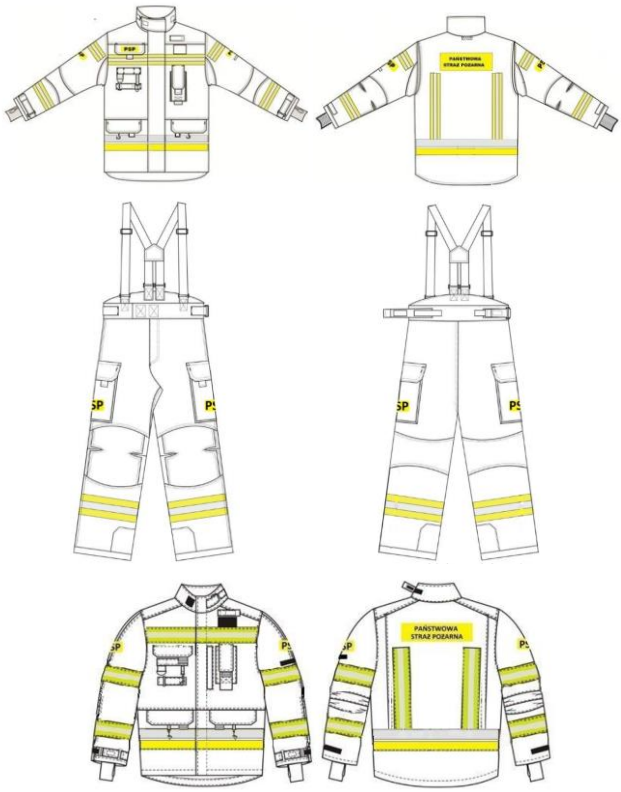
- **Selection of cooling methods during the firefighters' work is very limited. Firefighters are already exposed to heavy protective clothing and tools, and therefore, any extra burden is undesirable and must be avoided.**
- **The cooling strategy must at the same time be effective, quick and easy to use, and cannot expose worker to any additional load. The garments need to be washable and must be easy to take on and take off.**
- **The use of wearable electronics during the work of firefighters makes it possible to assess the physiological and thermal strain as well as performance in real time and thus prevent exhaustion.**

5 Requirements for protective clothing used by firefighters

Manufacturers of firefighters clothing who offer their products on the European Union market, must fulfil the conditions specified in THE REGULATION (EU) 2016/425 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2016 on personal protective equipment and repealing Council Directive 89/686/EEC. The most important to meet are the requirements of EN 469 standard **Protective clothing for firefighters - Performance requirements for protective clothing for firefighting.**

Additional restrictions for firefighters clothes (such as: construction, colour, clothing design) may result from national legal regulations.

Table 1 National legal regulations

Country	Selected restrictions
POLAND	Certificate CE, Certificate of Admission: CNBOP-PIB[1], Special clothing (jacket and trousers) and light jacket[2]  Outer fabric is yellow, black or dark navy without information about the composition of the fabric but meeting the requirements inter alia EN 469 standard and EN 15614 standard (light jacket)
FINLAND	Certificate CE, EN 469 and EN 15614 standards Special clothing (jacket and trousers) and light clothing (jacket and trousers) e.g. Clothing type 1 Surface material PBI or similar (at least 55 % para-aramid); General color "Gold" yellow or similar light yellow; Total weight of the textile structure max 500 g/m^2, insertion liner is not allowed. Clothing type 2 Jacket and trousers, surface fabric Hainsworth TITAN or similar (minimum 85 % aramid). General colour blue/black, red and gold. Total weight of the fabric structure max. 515 g/m^2. Other requirements same as in type 1.

[1] Scientific and Research Centre For Fire Protection - National Research Institute

[2] According to Regulation No. 9 of the Chief Commander of the State Fire Service of 17 July 2018 amending the ordinance on standards and detailed requirements, technical and quality features of uniforms, special clothing and personal protective equipment used in PSP, Technical Data Sheet KT-43

Country	Selected restrictions
	Clothing type 3 Jacket and trousers, surface fabric Nomex III or similar. Total weight of the fabric structure max. 565 g/m^2. Jacket: colour blue/black and red. Trousers: colour blue/black. Clothing type 4 (light): Jacket and trousers: surface fabric material GORE-TEX VARDE 2L or similar. Jacket colour blue/fluorescent yellow, orange and yellow. Trousers blue/fluorescent yellow.
SPAIN	The national legal requirements are not at that level of detail. The general rule is to ask for compliance with European regulations and harmonized standards (certificate CE). It can be up to the collective bargaining between the administrations and the fire services, or directly requested by fire services when asking for offers in public biddings for purchasing protective clothing, but this happens at local or provincial levels. Those local bodies are able to ask for particulars issues if they wish.

6 Products of the project

- The final report
- Short report in national language
- Article
    - *Assessment of comfort and ergonomics of protective clothing by physiological parameters for firefighters in Europe – a literature review*
    - *Smart solutions for firefighters to reduce thermal strain*
    - *Special firefighters clothing's requirements in Finland, Poland and Spain* (journalistic)
- A brochure (brief summary).

7 Summary

Comprehensive literature survey and analysis were performed. Altogether 45 articles were analysed. Years of publication were limited from 2000 to 2019. High thermal stress is evident when using protective clothing for firefighters (regardless of the methodologies or test conditions). Development of the lighter protective clothing is still needed. Specific requirements for underwear worn under firefighter's clothing is needed. To improve thermal comfort, new and intelligent solutions in clothing should be developed and applied. The cooling

strategy must at the same time be effective, quick and easy to use, and not exposing the worker on any additional load. Garments must be easy to dress on and off, and they also need to be washable.

8 Acknowledgements

This report has been based on the results of a research task carried out within the scope of the fourth stage of the National Programme "Improvement of safety and working conditions" partly supported in 2017–2019 — within the scope of state services — by the Ministry of Family, Labour and Social Policy. The Central Institute for Labour Protection – National Research Institute is the Programme's main co-ordinator.

Fire Protection Fund in Finland and Finnish Institute of Occupational Health in 2018.