Specialised Clothing for Firefighters in Poland – a Comparison of the Latest Set with the One Currently Used

Magdalena Młynarczyk, Katarzyna Zielińska

Central Institute for Labour Protection – National Research Institute, Czerniakowska St. 16, 00-701 Warsaw, Poland. E-mail: m.mlyynarczyk@ciop.pl

DOI: 10.5604/01.3001.0014.0942

Abstract
Specialist clothing for firefighters must comply with a number of various standards in terms of e.g. water vapour resistance. The use of different materials and constructional solutions may affect the results of thermal parameters of the clothing. A search for new solutions can lead to ergonomic products. The aim of the article was to show whether there were differences in thermal parameters between the special clothing currently used for firefighters in Poland and clothing that takes into account new materials and trends in the construction of the above-mentioned type of clothing. The research results indicate no difference between the sets of clothing tested in terms of global thermal parameters; however, differences are recorded for values of local thermal insulation and water vapour resistance. These differences are attributable mainly to the construction of the clothing and not to the materials used.

Key words: firefighter, special clothes, thermal manikin, thermal parameters.

Introduction
As a firefighters’ job is considered as one of the most dangerous professions, appropriate and comfortable protective clothing is essential. The State Fire Service in Poland gives numbers concerning, among other things, fire incidents. Only in 2017, in general, 1196158 firefighters intervened in 125892 incidents, from which 5116 are considered as medium, 298 as big, and 70 as large [1]. A medium fire means that objects, parts of objects, chattels, material storages, machines, devices and/or raw materials with an area of (71-300) m² or a volume of (351-1500) m³ are destroyed as a result [2]. Considering the most common materials that burn during incidents (e.g. the maximum diffusion flame temperature, varies from 1027 °C for wood to 1200 °C for methanol [3]), firefighters are exposed to heat stress. The common and frequent exposure to high temperatures can cause extremely high thermal stress and overheating, which are life-threatening regarding their circumstances. These factors make this area of protective clothing interesting for global as well as local producers. The number of the latter in Poland is currently increasing. Besides the obvious functions that thermal clothing fulfils, it also needs to comply with strict standards. All personal protective equipment used by firefighters (including special clothing) is classified as Category III. The result of this process is the EC type-examination certificate, which confirms compliance with the requirements of Directive 89/686/EEC[1] [4], in particular the EN 469 standard [5]. These requirements are essential when choosing appropriate equipment. Producers, trying to fulfil all of them, offer many different types of clothing. Models of protective clothing differ from each other with respect to their construction, number of layers and, most importantly, the materials that they are made of. The many combinations of different fibres used for thermal clothing imply a great number of fabrics that have protective properties.

Unfortunately, most of them, aside from insulating from outside heat, also do so from the heat produced by humans, causing a disturbance in thermal comfort as well as overheating of the firefighter’s organism. The weight of sets also needs to be mentioned, as they are usually quite heavy, which makes the work even more difficult and tough. Optimal protective clothing, therefore, needs to insulate against the outside temperature, highly reduce heat transfer, and be light and comfortable for its user.

Main goal of research
The main goal of the research presented in the article was to show whether there were any differences in thermal parameters between the special clothing currently used for firefighters in Poland (EN_1) and clothing that takes into account new materials and trends in the construction of the above-mentioned type of clothing (EN_2).

The results of our research could answer the question whether the construction or material used in special clothing have an influence on thermal parameters. Indirectly, it could allow to state how to improve new patterns of special clothing.

Material and methods
Research equipment
The study was carried out with a thermal manikin of the Newton type manufactured by Measurement Technology Northwest (USA). The manikin consists of 32 segments (Figure 1). The thermal manikin allows simulation of dry heat transfer (thermal insulation) as well as wet heat transfer (evaporative resistance) [6].

Figure 1. Scheme of thermal manikin’s segmentation (from left: front and back of the manikin).
The clothes tested differed in terms of the materials used for each layer of the structure. A summary of materials used for the clothing ensembles tested is shown in Table 1.

Table 1. Materials used for the clothing ensembles tested (data from the producer).

<table>
<thead>
<tr>
<th>Layer</th>
<th>EN_1</th>
<th>EN_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>External</td>
<td>64% meta-aramid, 35% para-aramid, 1% anti-static fibres</td>
<td>70% meta-aramid, 28% para-aramid, 2% anti-static carbon fibre</td>
</tr>
<tr>
<td>Membrane</td>
<td>35% polyurethane, 65% para-aramid</td>
<td>50% laminate PTFE, 25% meta-aramid, 25% para-aramid</td>
</tr>
<tr>
<td>Thermal insulation</td>
<td>aramid flame retardant fibres</td>
<td>67% meta-aramid, 33% para-aramid</td>
</tr>
<tr>
<td>Lining</td>
<td>50% aramid fibre, 50% viscose</td>
<td>93% meta-aramid, 5% para-aramid, 2% anti-static fibres</td>
</tr>
</tbody>
</table>

Table 2. Weight of individual elements of the FFPPC garment.

<table>
<thead>
<tr>
<th>Layer weight, kg</th>
<th>EN_1</th>
<th>EN_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blouse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>external layer</td>
<td>1.235</td>
<td>1.860</td>
</tr>
<tr>
<td>thermal insulation and lining layer</td>
<td>0.826</td>
<td>1.216</td>
</tr>
<tr>
<td>Pants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>external layer</td>
<td>0.618</td>
<td></td>
</tr>
<tr>
<td>thermal insulation and lining layer</td>
<td>0.547</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Microclimate parameters in the climatic chamber during testing of the thermal insulation of the clothing ensembles (mean values with standard deviation for two microclimate meters).

<table>
<thead>
<tr>
<th>Clothing ensemble FFPPC</th>
<th>EN_1</th>
<th>EN_2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$t_p$, °C</td>
<td>$V_e$, m/s</td>
</tr>
<tr>
<td>EN_1</td>
<td>test_1</td>
<td>12.4 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>test_2</td>
<td>12.4 ± 0.1</td>
</tr>
<tr>
<td>EN_2</td>
<td>test_1</td>
<td>12.4 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>test_2</td>
<td>12.4 ± 0.1</td>
</tr>
</tbody>
</table>

Table 4. Microclimate parameters in the climatic chamber during testing of the evaporative resistance of the clothing ensembles (mean values with standard deviation for two microclimate meters).

<table>
<thead>
<tr>
<th>Clothing ensemble FFPPC</th>
<th>EN_1</th>
<th>EN_2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$t_p$, °C</td>
<td>$V_e$, m/s</td>
</tr>
<tr>
<td>EN_1</td>
<td>test_1</td>
<td>12.3 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>test_2</td>
<td>12.2 ± 0.1</td>
</tr>
<tr>
<td>EN_2</td>
<td>test_1</td>
<td>12.2 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>test_2</td>
<td>12.2 ± 0.1</td>
</tr>
</tbody>
</table>

The tests were done in a climatic chamber (Weiss). Microclimate parameters like air temperature ($t_p$), air velocity ($V_e$) and relative humidity (RH) were controlled by two microclimate meters: Indoor Climate Analyzer from B&K and INNOVA.

Tested clothing

Two sets of special clothing (Firefighters Personal Protective Clothing – FFPPC) intended for firefighting and similar actions, such as rescue and disasters, were used. One of them (EN_1) is currently used in Poland (Figure 2), while the other is a new design (EN_2) meeting the requirements of EN 469 [5] while using the latest trends. The EN_2 garment has a high-quality membrane and perforated reflective tapes. Such types of tapes do not stop water from evaporating, therefore the clothing ability to “breathe” is enhanced. Furthermore, perforated reflective tapes affect the mass of the clothes. The clothing has an EC type examination certificate and the CNBOP-PiB Certificate of Approval[2].

The clothes tested differed in terms of the materials used for each layer of the structure. A summary of materials used for the clothing ensembles tested is shown in Table 1.

Individual layers of the firefighter special clothing differed mainly in the percentage of each aramid isomer and the materials used in the lining layer.

The above sets of clothing also differed in mass. Detailed information is provided in Table 2.

The EN_2 set was 150g lighter than the EN_1. Lighter clothing, being a lower burden for the user; which improves ergonomics and comfort of use.

Thermal parameters of FFPPC

Thermal insulation $R_{ct}$

Thermal insulation tests of the clothes selected ($R_{ct}$) were conducted in accordance with the EN ISO 15831:2004 [7] and EN 342:2004 [8] standards. During the tests, the thermal manikin was wearing a special fabric skin, and its surface temperature was set at 34.0 °C. According to EN ISO 15831:2004 [7], the permitted error between measurements is 4%.
The insulation tests were carried out in an environmental chamber with the parameters set as follows: air temperature \( t_a \) 12 °C, relative humidity (RH) 45%, and air velocity \( V_a \) 0.4 m/s. The tests were done in steady-state conditions, and the thermal parameters in the climatic chamber were controlled by microclimate meters (Table 3).

**Evaporative resistance \( R_{cti} \)**

The evaporative resistance of the clothing ensemble \( R_{cti} \) was tested on a thermal manikin wearing a special fabric skin. The test conditions complied with the ASTM F2370-15 standard [9]. During the tests, the manikin surface temperature for most segments was 34.0 °C and the sweat rate – 400 ml/(h·m²). According to ASTM F2370-15 [9], the permitted error between measurements was 10%.

As required, they corresponded to the ‘non-isothermal conditions’ under the same conditions as for dry heat exchange. The thermal parameters in the climatic chamber were controlled by microclimate meters (Table 4).

**Results**

Results from the thermal insulation and evaporative resistance tests performed for the clothing selected are presented below.

**Total thermal insulation**

A summary of the total thermal insulation (calculated by two mathematical methods [6, 7]: the thermal insulation was calculated by two mathematical methods: serial \( R_{cti_{serial}} \) – as the sum of the thermal insulation calculated for individual segments, and parallel \( R_{cti_{parallel}} \) – treating the thermal manikin as a whole (as one segment), is shown in Table 5.

In order to find out whether the use of other materials affected the thermal resistance, despite the approximate final \( R_{cti} \) value, the local thermal insulation \( R_{cti} \) was calculated for selected segments of the manikin where the clothing tested had a direct influence on the manikin, such as the head, face, hands and feet (Figure 3).

The percentage difference (PD) measured by the local \( R_{cti} \) was calculated (according to Equation (1)) for selected segments of the manikin for 2 sets of clothing.

\[
PD = \frac{R_{cti}(EN_2) - R_{cti}(EN_1)}{R_{cti}(EN_2)} \cdot 100\% \\
= \left(1 - \frac{R_{cti}(EN_1)}{R_{cti}(EN_2)}\right) \cdot 100\% \tag{1}
\]

where:

- PD – percentage difference, %
- \( R_{cti}(EN_1) \) – local thermal insulation for selected segments of the manikin for ensemble 1, m² °C/W
- \( R_{cti}(EN_2) \) – local thermal insulation for selected segments of the manikin for ensemble 2, m² °C/W.

The difference (PD values) is shown in Figure 4.

![Figure 3. Local thermal insulation (Rcti) for selected segments.](image)

![Figure 4. Percentage difference (PD according to Equation (1)) in local thermal insulation Rcti between the ensembles tested.](image)

**Table 5. Total insulation (Rcti) of the special clothes: mean values with standard deviation (SD).**

<table>
<thead>
<tr>
<th>Clothing ensemble</th>
<th>test_1 ( m^2 \cdot °C/W )</th>
<th>test_2 ( m^2 \cdot °C/W )</th>
<th>mean value ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN_1</td>
<td>0.420</td>
<td>0.424</td>
<td>0.422 ± 0.003</td>
</tr>
<tr>
<td>EN_2</td>
<td>0.416</td>
<td>0.424</td>
<td>0.420 ± 0.006</td>
</tr>
</tbody>
</table>

\( R_{cti_{parallel}, m^2 \cdot °C/W} \)

<table>
<thead>
<tr>
<th>Clothing ensemble</th>
<th>EN_1</th>
<th>EN_2</th>
<th>mean value ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN_1</td>
<td>0.262</td>
<td>0.263</td>
<td>0.263 ± 0.001</td>
</tr>
<tr>
<td>EN_2</td>
<td>0.272</td>
<td>0.273</td>
<td>0.272 ± 0.001</td>
</tr>
</tbody>
</table>
The PD values could inform as to which segment possessed significant differences, and the PD ’sign’ shows where the higher value was obtained. For a percentage difference >0%, higher local thermal insulation values were recorded for EN_2, for a percentage difference <0% – higher local thermal insulation values were recorded for EN_1. The differences obtained are marked schematically in Figure 5.

Differences of >4% (where the difference is significant) were recorded on many segments. Higher values of local thermal insulation for EN_2 were recorded mainly on segments located on the front of the manikin at hip level (17_waist, 19-21_upper thighs ((front)), shank (27-29_calf ((front)) and on the back (16_midle back). On the other hand, higher values of local thermal insulation for EN_1 were recorded mainly on the front of the manikin on the chest and abdomen (13_upper chest, 15_stomach), and on the back of the manikin on the shoulder and hips (14_shoulder, 18_lower back, 20_upper thigh ((back)). Also, on the segments located at thigh level (23-26_thigh ((front and back)), the differences in local thermal insulation are due to the difference in the length of the jacket of the special clothing. For EN_1, it covers a larger proportion of the thighs than for EN_2.

According to the manufacturer, EN_2 uses materials with a basis weight lower than 500 g/m², therefore for the above-mentioned set of clothing, the thermal insulation should be lower. For the construction of clothing, however, material with very high resistance to mechanical damage was used to reinforce, among others, the arms, elbows, knees, leg pockets and sleeve pockets. Therefore, the above-mentioned areas have higher local thermal insulation values for EN_2. The differences recorded may also be related to the fitting of the clothing tested to the manikin’s body, as well as to the type of membrane used in the clothing. It should be noted, however, that globally the thermal insulation values of the entire products EN_1 and EN_2 are similar to each other.

**Evaporative resistance**

Evaporative resistance shows how easily water vapour can diffuse through the material. There are three classes of water vapour permeability [10]: 1st \( R_{ct} > 0.040 \text{ m}^2\text{kPa/W}, 2\text{nd} 0.020 \text{ m}^2\text{kPa/W} < R_{ct} \leq 0.040 \text{ m}^2\text{kPa/W} \) and 3rd \( R_{ct} \leq 0.020 \text{ m}^2\text{kPa/W}. \) Membranes with high evaporative resistance (1st class membrane) are unfit for a long wear hence, the wearing time has to be restricted.

In our research, evaporative resistance tests of the clothing (\( R_{ct} \)) were carried out for an assumed intensity of sweating equal to 400 ml/(h · m²). A summary of the evaporative resistance of the tests is shown in Table 6.

\( R_{ct} \) values for individual sets of special clothing were similar (Figure 6). The maximum difference between the results was <10%, i.e. below the permissible error between evaporative resistance tests [9].

The clothing layer which has a big impact on the evaporative resistance is the membrane.

In our research, the membrane used (EN_1: 65% para-aramid, 35% polyurethane (PU)); EN_2: 50% laminate PTFE 25% meta-aramid, 25% para-aramid; see

**Table 6. Mean values of the evaporative resistance \( R_{ct} \) of the ensembles, tested with standard deviation (SD).**

<table>
<thead>
<tr>
<th>Clothing ensemble, ( R_{ct} ) m²kPa/W</th>
<th>test_1</th>
<th>test_2</th>
<th>mean value ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN_1</td>
<td>0.0351</td>
<td>0.0347</td>
<td>0.0349 ± 0.0003</td>
</tr>
<tr>
<td>EN_2</td>
<td>0.0371</td>
<td>0.0394</td>
<td>0.0383 ± 0.0016</td>
</tr>
</tbody>
</table>
Table 1), as well as other layers of the clothing did not significantly affect the evaporative resistance.

The local evaporative resistance ($R_{ett}$) was calculated for selected segments of the manikin where the clothing tested had a direct influence on the manikin, such as the head, face, hands and feet (Figure 7).

The results obtained, shown in Figure 7, highlighted that on some segments differences in $R_{ett}$ occurred. The percentage difference (PD) measured by local $R_{ett}$ was calculated (according to Equation (2)) for selected segments of the manikin for 2 sets of clothing.

\[
PD = \frac{R_{ett}(EN_2) - R_{ett}(EN_1)}{R_{ett}(EN_2)} \cdot 100\%
\]

where:
- PD – percentage difference, %
- $R_{ett}(EN_1)$ – local thermal insulation for selected segments of the manikin for ensemble 1, m²kPa/W
- $R_{ett}(EN_2)$ – local thermal insulation for selected segments of the manikin for ensemble 2, m²kPa/W.

The difference in PD values is shown in Figure 8.

For a percentage difference $> 0\%$, higher local thermal insulation values were recorded for EN_2, while for a percentage difference $< 0\%$, higher local thermal insulation values were recorded for EN_1. The differences obtained are marked schematically in Figure 9.

On many segments, the differences were $>10\%$, mainly on the back of the manikin.

Despite the use of a better membrane, higher values of local water vapour resistance for EN_2 were recorded mainly on segments located on the back (14_shoulder, 16_middle back, 18_lower back) and on the front of the manikin at hip height (17_waist, 19-21_upper thighs ((front))). However, it must be borne in mind that additional reinforcing material was used in the EN_2 clothing structure, which also affects the evaporative resistance. On the other hand, higher values of local water vapour resistance for EN_1 were recorded mainly on the back of the manikin on the thighs (22_upper thigh, 24-26_lower tights ((back)) and at abdominal height (15_stomach).

Discussion and summary

The thermal parameters of the specialised firefighter clothing presented herein, such as the thermal insulation and evaporative resistance, were measured. Based on the analysis and calculations of the test results, it has been shown that the special clothing for firefighters provides a barrier to heat exchange between the user and the surrounding environment.

According to the normative requirements, there are no limit values for the thermal insulation of such a type of clothing. This is due to the fact that clothing intended for firefighters should be used regardless of weather conditions. The mean value of the clothing’s total thermal insulation and evaporative resistance obtained from the tests are (0.421 ± 0.004) m²°C/W and (0.0366 ± 0.0022) m²kPa/W. The research has shown that the clothing construction has a greater influence on local values of thermal parameters of the clothing when materials with similar properties are used.

Similar results were obtained by Zhu et al. [11]. The thermal insulation for a material construction consisting of an aramid (outer shell), a PTFE (polytet-
For a percentage difference $>0\%$, higher local thermal insulation values were recorded for

In our research, the differences in $R_{et}$ observed may result not so much from the type of membrane used but from the material to which it was applied. The PU and PTFE membranes have similar properties; however, it should be remembered that the vapour resistance of breathable membranes and coatings is applied [12]. The differences observed may also result from matching the clothing tested to the manikin’s body. The EN_2 jacket was shorter and better adhered to the measuring surface of the manikin. However, globally, the water vapour resistance values of the entire EN_1 and EN_2 products are similar. According to [12] the vapour resistance of breathable membranes and coatings is influenced by the fabric substrate to which they are applied. Considering the great effort during firefighters’ work, particular analysis should be dedicated to water vapour permeability. Appropriate material used for protective clothing can significantly reduce thermal discomfort while keeping the basic properties of thermal insulation as well as chemical and mechanical resistance.

**Acknowledgements**

This paper was 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.

**References**

5. EN 469 Protective clothing for firemen.
10. EN 343 Certified Worker for Protection From Rain.

---

**Editorial notes**

2) CNBOP-PiB – Scientific and Research Centre for Fire Protection – National Research Institute is a Scientific Unit in Poland with the mission of ensuring the public safety of the Country in terms of fire protection, crisis management, civil protection and civil defence.