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# THERMAL IMAGING FOR THE OPERATOR'S COMFORT ASSESSMENT IN THE ASPECT OF THE COVID-19 PANDEMIC

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## *Abstract:*

*The article aims to preliminary analyze and identify the working conditions of an operator wearing disposable personal protective equipment and features and usability of the suit. The characteristics of the thermal image for an operator wearing a personal protection suit will be used as part of the IT system for comfort assessment. The system will allow the assessment of the operator's comfort based on thermograms. It will also detect dangerous situations resulting from the operator's work in such an outfit or overalls. The hazardous conditions for operators are related to the symptoms of thermal discomfort leading to overheating the body and, consequently, fainting. These situations may cause accidents and reduce the quality of the activities performed. The current legal status was considered when referring to selected social aspects in the management and quality of work of an operator wearing a COVID-19 protective suit. References are made to documents on legislative acts in Poland and Europe to limit the risk from biological agents. This part of the article refers to a vital study by Majchrzycka and Okrasa (2019, the Central Institute for Labor Protection - National Research Institute) presenting the rules for the safe use of non-biocidal respiratory protective equipment. This included obligations of the employer. The employer is obliged to take preventive measures against exposition of employees to harmful biological agents, including airtight measures and personal protective equipment. The article emphasizes selected medical aspects of working in personal protective clothing during the COVID-19 pandemic. Referring to the study (Sobolewski, 2014), according to the authors, the presented case reflects the working conditions of an operator wearing a disposable protective suit. Microclimate parameters and changing metabolism define the hot thermal environment in the mentioned standard. The article presents the results of thermovision inspection of the operator of technical means of transport working in a suit protecting against COVID-19 infection, constituting one-off personal protection. The individual elements included in the protective set of disposable personal protection have been described. The following research stage is preparing thermograms, which show the operator in a protective case before, during, and after work. Thermograms have been classified and commented on.*

**Keywords:** *transport vehicles operator, COVID-19, thermal imaging, thermal comfort*

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## 1. Introduction

The COVID-19 epidemic is a new social experience that has resulted in the development of knowledge based on new experiences and needs caused by the epidemic. These experiences, in turn, result from the need to protect people from the pathogen causing the disease, while keeping the ability to work and function normally. This applies particularly to operators of means of transport and various types of technical equipment necessary to ensure normal living conditions for societies. The presence of operators or drivers in the vicinity of people infected with the COVID-19 virus (and possibly other types of pathogens in the future) is necessary due to their unique skills and authorizations required for a given activity or transport. As it is not possible to eliminate the presence of people: operators and drivers, especially in health care, it is necessary to reduce the risk of contamination by creating barriers that are impenetrable to the virus.

Thermal comfort and the related comfort resulting from body perspiration, limited mobility, and visibility are key factors determining the efficiency of the employee and the safety of the work performed, e.g., transport. The pandemic conditions forced the use of protective clothing on a large scale. However, due to the urgent need to use it, no dedicated research was conducted on the impact of such clothing on efficiency and safety at work. This situation, however, provided a relatively large sample of cases that could be analyzed and referred to. Thermography is considered an effective tool in research on work comfort, especially when combined with medical knowledge of the influence of higher temperature on the well-being of workers/operators, their motor and psychophysical abilities, and endurance.

This article analyzes the working conditions of operators of technical equipment or drivers who are forced to perform their duties in a full protective suit. The protective suit meets the requirements necessary to protect against infection with the pathogen causing COVID-19. Thermography depicting the temperature distribution of an employee's body dressed in a suit is used for the study. On this basis, conclusions were made about the possible consequences of using such garments on a larger scale.

The remainder of this article is composed as follows. Section 2. presents a literature review on thermal imaging and its applications to COVID-19-related problems. Sections 3. and 4. touch the issues of regulations concerning working in the COVID-19 protective suit and medical aspects of working in a personal protective suit. Section 4. presents the thermograms of the operator in different stages of the work and the operator's clothes after taking off the protective suit. Thermograms have been classified and commented on in Section 5.

## 2. Literature review

Thermal imaging is when a camera captures an image of an object or person emitting infrared radiation. Thermographic cameras usually use long-infrared range radiation (about 9–14 μm) to make thermograms. The amount of radiation an object emits increases with temperature; humans and other living creatures are incredibly convenient for thermal imaging. Thermography is also used to detect unwanted objects during airport check-in, in medicine procedures (Kylili et al. 2014), and to detect people with increased temperature suspected of being infected with a coronavirus or other pathogen (Flir, 2009) or (Bach et al., 2015).

Thermal imaging is of great importance in diagnosing construction defects. Thermal imaging was initially developed as a night vision and observation tool for the army. The use of thermal imaging systems for construction condition monitoring eliminates illumination-related problems that occur with light-based cameras. Thermal imaging applications for technical purposes are widespread. The authors of (Stypułkowski et al., 2021)present the application of thermal imaging to detect malfunctions in railway electric heating devices. Netzelmann et al. (2016) proposed a survey on induction thermography for surface defect detection in forged elements and a crack detection method in railway components. These are just two of many different studies on thermal imaging for transport and engineering applications.

Barnawi et al. (2021) present a very interesting AI-enabled IoT-based system for COVID-19 scanning. They propose a learning-based scheme designed for patient scanning and classification. The scanning is performed through thermal cameras, but this usage of thermograms, although related to a pandemic situation, is not as presented in this article.

Studies on the impact of COVID-19 on traveling and the life of people became a popular topic when the

epidemics started. Authors investigate the conditions and comfort of traveling in different areas. Beck and Hensher (2021) point to failed quarantine procedures for travelers returning from overseas. They discuss what the future transport policy is and how it can regulate the safety of traveling. Budd and Ison (2020) propose an academic concept of Responsible Transport, which defines the role of the individual as a responsible actor in delivering socially desired transport outcomes. Jenelius and Cebecauer (2020) show that public transport has been hit hard by COVID-19 compared with other modes, and safety was a significant aspect of that issue. Fumagalli, Rezende, and Guimarães (2021) discuss a demand control equalizing the number of passengers in each car, respecting the COVID-19 social distancing protocols. Beck, Hensher, and Nelson (2021) find out that concerns over bio-security issues around public transport are enduring, and concern about hygiene is significantly negatively related to public transport use. This forces the research on potential securing methods to keep the driver safe. Considerations of this type may also be a microscale element of the urban mobility rules and be the subject of a multi-criteria assessment to ensure comfort in transport (Cieśla, Sobota and Jacyna, 2020) and should be considered in the models for testing reliability of transport services (Jacyna and Żak, 2016), reliability of services, as presented in Jacyna and Semenov (2020) and Rudyk et al. (2019) or risk assessment like presented by Szaciłło et al. (2021).
Thermal imaging is commonly used for comfort assessment, especially in assessing the thermal control of the human body in different conditions. Bach et al. (2015) use thermal imaging for measuring body temperature during rest, exercise in the heat, and recovery, but they don't focus on clothing. Ring et al. (2015) discuss thermographic fever scanning. De Oliveira et al. (2007) use infrared imaging analysis for thermal comfort assessment. Authors study face thermographic imaging with different areas of interest: left and right front, cheek, and periorbital region. They examine areas of interest by the Fast Fourier Transform (FFT). Ordun, Raff and Purushotham (2020) use thermal imaging for emotion recognition while Farooq and Corcoran (2020) for breast tumor classification. Human thermal comfort is analyzed through facial infrared thermography also by Li, Menassa and Kamat (2018). Metzmacher et al. (2018) explore thermal comfort assessment by real-time scanning. The authors of this work merge optical data and conventional sensor input for advanced thermal comfort analysis. They obtain a complete representation of a person in various indoor conditions. The authors propose a method for combining depth-map-based face and pose tracking with thermal imaging. Burzo et al. (2014) use thermography to detect thermal discomfort in a building's inhabitants. The thermal comfort can be treated in the future as one of the parameters to be recorded by vehicle control systems on the railway (Jacyna et al., 2018) or in the applications of Internet of Things (Lewczuk and Kłodawski, 2020).
A different part of the literature concerns the security equipment for personal usage in the COVID-19 pandemic. Babaahmadi et al. (2021) review a series of materials and technologies for masks and propose functions of a high-performance face mask in a respiratory pandemic. They touch the problem of comfort only partially. Garibaldi et al. (2019) discuss novel personal protective equipment coverall, similar to one presented in this article, and provide exciting parameters of use, including comfort, but don't show the operator's problems of technical equipment or vehicles.
A significant information related to the topic of this study: the design and features of individual protective suits and their use is provided in the official documents presented in chapters 3 and 4.

## 3. Management and quality regulations concerning working in the COVID-19 protective suit

Legislative actions aimed at limiting the risk from biological agents are regulated in Poland by the Regulation of the Minister of Health (Ministry of Health) of April 22, 2005, on harmful biological agents for health in the work environment and protection of the health of workers professionally exposed to these factors (RoMH, 2008). The document implements to the Polish law the provisions of Directive 2000/54/EC of the European Parliament and the EU Council of September 18, 2000 (DEC, 2000). Following the Regulation of the Minister of Health, the employer is obliged to take preventive measures against employees exposed to harmful biological agents, including the use of airtight solutions, including personal protective equipment. In the case of workers' exposure to inhalation of harmful bioaerosol, it is a respiratory system protection equipment.

The primary legal act regulating the use of personal protective equipment is the Labor Code (LC, 2020). Under the Art. 2376, p. 1, the employer is obliged to provide the employee with free personal protective equipment against hazardous and harmful factors in the work environment and inform the employee about using these means. According to p. 3, the employer's protective equipment should meet the conformity requirements specified in separate regulations. In practice, for the employer and user, this means that they should be CE marked, which confirms compliance with the Regulation EU 2016/425 (EU, 2016) of the European Parliament and the Council and the relevant standards.

Filtering respiratory protection equipment is described by the following standards: (UNE EN 149:2001+A1:2010) and (DIN EN 143:2021-07). At the same time, following the regulation of the Minister of Labor and Social Policy (MoLSP, 2003), the employer should ensure that the personal protective equipment allocated to employees is appropriate to the existing threat and does not increase the risk. The respiratory system protection equipment against harmful bioaerosol, in addition to its high capacity to capture fine dispersion particles, should have biocidal properties, or the employer should establish the rules and time of safe use of standard equipment. With its long-term use in the environment of microorganisms, their number may increase, and the biofilm in filtration nonwoven may form, which may be a potential source of danger for the equipment user.

Before selecting respiratory protection equipment (Majchrzycka and Okrasa, 2019), the employer must assess the occupational risk related to workers' exposures to inhalation of harmful bioaerosol.

For this purpose, the employer should gather information on harmful biological agents present at workplaces, taking into account:

- classification and list of harmful biological agents contained in the ordinance of the Minister of Health,
- type of professional activities performed by the employee as well as the time and degree of exposure to biological agents,
- possibility (probability) of an allergenic or toxic effect of a harmful biological agent,
- the type of disease that may occur to the employee as a result of the work performed,
- analysis of cases of occupational diseases that were directly related to the performed work in conditions of exposure to biological agents,
- recommendations of the sanitary inspection authorities, units of the occupational medicine service, or the National Labor Inspectorate.

Rules for the safe use of non-biocidal respiratory protective equipment should be focused on minimizing the possibility of the spread of biological agents by (Majchrzycka and Okrasa, 2019):

- disposal of equipment after each activity related to the harmful bioaerosol,
- disposal of equipment when it becomes contaminated with blood or other physiological fluids,
- disposal of equipment after direct contact with the person being the source of the infection that requires special precautions,
- use of a face shield in addition to respiratory protection equipment, if this will reduce the contamination of the filtering surface of the equipment with microorganisms,
- storage of the equipment when not used in a designated room, in a paper, air-permeable container,
- preventing contact of persons other than the user with the contaminated surface of the equipment when the equipment is not used, e.g., by introducing codes identifying the equipment and preventing unauthorized access to the room in which it is stored,
- regular cleaning of containers (other than paper ones) for storing equipment during breaks at work or the use of single-use containers,
- washing hands with water and soap or alcohol-based disinfectants before touching and after touching the equipment when putting it on, taking it off or adjusting it,
- avoiding touching the inside of the equipment; disposable non-sterile protective gloves may be used for this purpose and should be discarded after putting on, taking off, or adjusting the equipment.

## 4. Medical aspects of working in a personal protective suit

The case described in publication (Sobolewski, 2014), according to the authors, reflects the working conditions of an operator in a disposable protective suit. Values of local microclimate parameters included in the range of variability assigned to the hot environment - case report (Sobolewski, 2014).

A unique feature of the hot environment is how heat release from the human body to the environment is possible only through sweat evaporation. The temperature of the skin surface is often lower than the ambient temperature. The discussed procedure assumed that work in a hot environment is a short, several-minute episode when the employee stays at a position located in the local microclimate (MKL) with these properties. The air temperature in this environment reaches the highest value among the remaining MKLs.

The method included in the UNE EN ISO 7933:2005 was used to assess the heat load of the human body in a hot environment.

The hot thermal environment in the mentioned standard is defined by the microclimate parameters and metabolism changing in the ranges shown in Table 1.

Table 1. Variability ranges for microclimate and metabolism parameters in a hot thermal environment adopted in the UNE EN ISO 7933:2005

| Parameter | Description | Variation range |
|---|---|---|
| $M$, W/m$^2$ | metabolism | $100 \leq M \leq 450$ |
| $I_{cl}$, m$^2$ · K/W (clo) | basic thermal insulation of clothing | $0{,}0155 \leq I_{cl} \leq 0{,}155$ $(0{,}1 \leq I_{cl} \leq 1)$ |
| $t_a$, °C | ambient air temperature | $15 \leq t_a \leq 50$ |
| $t_r - t_a$, °C | difference between radiation temperature and air temperature | $0 \leq t_r - t_a \leq 60$ |
| $v$, m/s | airflow speed | $0 \leq v \leq 3$ |
| $p_a$, P$_a$ | the partial pressure of water vapor | $0 \leq p_a \leq 4500$ |

The permissible time of an employee's exposure to a hot environment is calculated using software, which source is provided by UNE EN ISO 7933:2005. Under the existing conditions and with a specific physical effort, it is an estimated working time that will elapse from the moment of commencement of work to the moment when the internal temperature of the body of an employee wearing clothing with $I_{cl\ opt}$ insulation reaches 38 °C.

Based on the calculations, diagrams were prepared to determine the allowed exposure time of the employee $\tau_{lim}$ (Y-axis of the diagram), dressed in clothing with insulation $I_{cl}$ opt = 0.6 and 1 clo, with energy expenditure $M$, depending on temperature and relative humidity air rh (X-axis). The calculations were made for the metabolic rate M = 100, 150, 200, 250 W/m$^2$. An example of a diagram for determining the allowed exposure time as a function of four variables: $I_{cl}$ = 1 clo, $M$ = 150 W/m$^2$, $t_a = t_r$, $rh$, is shown in Figure 1.

Curves in the diagram, marked with different colors, are isotherms (in °C). Isotherms reflect the relationships between the safe exposure time (labeled on the Y-axis; the minor scale corresponds to 10 min) with the conditions defined by four variables, i.e., the garment thermal insulation value $I_{cl\ opt}$ = 1 clo, metabolism $M$ = 150 W/m$^2$, temperature of the surrounding environment changing in the range of 27 °C $\leq t_a = t_r \leq$ 50 °C and relative air humidity in the range of 0% $\leq rh \leq$ 100% (X-axis).

The diagram shows (the center of the circle marked in Figure 1) that in garments with thermal insulation $I_{cl\ opt} \approx 1$ clo, at air temperature $t_a = t_r$ = 38 °C, with airflow velocity $v < 1$ m/s, humidity $rh$ = 60% and energy expenditure $M$ = 150 W/m$^2$, the permissible exposure time of the worker is 40 minutes. If the air humidity is $rh$ = 35%, the time is extended to 480 minutes. The diagrams developed for the local microclimate used to determine the permissible exposure time of a person wearing clothing with thermal insulation $I_{cl}$ = 1 clo, staying in a hot environment, additionally create the possibility of a general assessment of human heat load. The WBGT indicator is not suitable for this purpose. As is known, it is commonly used to assess the heat load acting on an employee in a hot environment within a few hours, but it allows the use of clothing with thermal insulation not exceeding 0.6 clo.

## 5. The operator's working conditions and personal protective equipment

The operator works 8 hours while wearing a protective suit and works 3 hours in two cycles, with an hour's break after every three hours. After each 3-hour shift, the protective suit is disposed of, except for the protective helmet sent for disinsection.

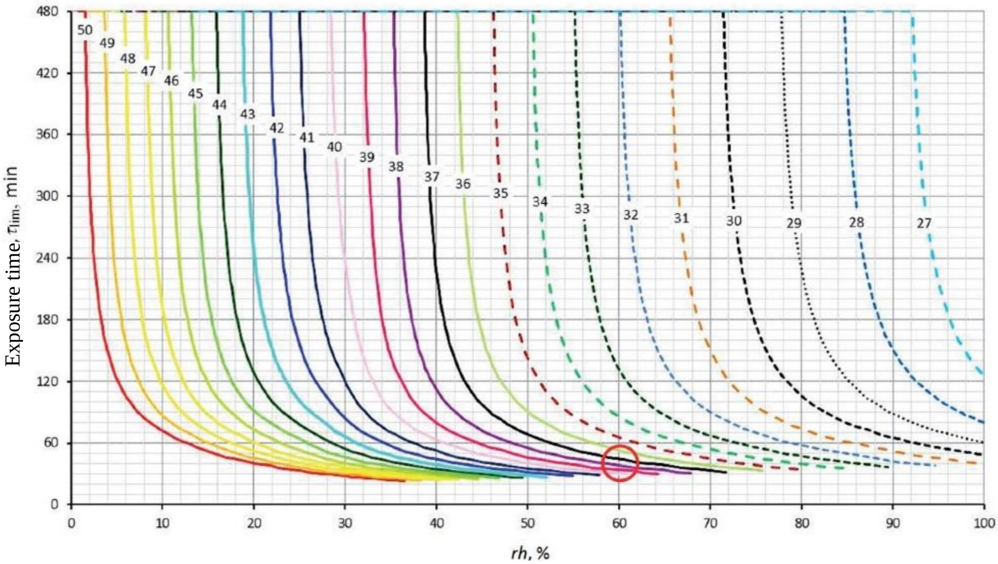



Fig. 1. Diagram for reading the allowed exposure time ($\tau_{lim}$) of an employee wearing clothing with thermal insulation $I_{cl}$ = 1 clo, staying in an environment with a temperature varying from 27 °C ≤ $t_a = t_r$ ≤ 50 °C and relative air humidity in the range of 0% ≤ $rh$ ≤ 100%, for energy expenditure $M$ = 150 W/m$^2$ (source: Sobolewski, 2014)

The set of disposable personal protective equipment shown in Figure 2a consists of:

- safety uniform,
- filtering half mask,
- latex, powder-free protective gloves,
- surgical cap,
- protective overlays for footwear,
- face shield, operator's helmet.

Employees undergo compulsory training on using a protective suit, putting on, working in this outfit, taking off (disinfection sluice), rest - break between turns. Requirements, selection, and use of protective suits during a pandemic are described, among others, by the Central Institute for Labor Protection (Bartkowiak and Dąbrowska, 2020).

Protective suit (Oxyline, 2021) OxyChem C310 in compliance with EN 13034: 2005 + A1: 2009, EN ISO 13982-1: 2004 + A1: 2010, EN 14605: 2005 + A1: 2009, EN 1073-2: 2002, EN 1149-5: 2018, EN 14126: 2003+: 2004, EN ISO 13688: 2013, provides limited type 4/5/6 chemical protection. Made of a fabric laminated with a microporous MPFL foil weighing 65 g/m$^2$, the outer layer is polyethylene foil. The inner layer is polypropylene fibers. This layer is resistant to infectious agents. In addition, the suit has taped seams so that the suit has the fourth level (type) of protection. The OxyChem C310 coverall also protects against radioactive dust and has anti-electrostatic properties. The structure provides the highest possible safety, ergonomics, and comfort during work. Product qualified for category 3 PPE, additional functional properties of the protective suit are taped seams, a three-panel hood, two-way zipper with adhesive flap, two-piece crotch, elastic cuffs, legs, waist and hood, elastic thumb loop, durable overlock seams on the inside, taped on the outside with blue tape. Figure 2a presents a photograph of an employee in a protective suit, taken in a break room before starting work, a 3-hour duty.

The filtering half mask (Figure 2b) is, apart from the protective suit, included in the disposable personal protection. Filtering half mask FS-O / 30V FFP3 NR D (Filter, 2021), category FS-O series, class P3, NDS 30 x NDS meeting the UNE EN 149: 2001 + A1: 2009 standard, by the certificate issued CIOP PIB following EU 2016 / 425.

The mask has a predetermined shape around the nose taken from the proven Simpla series (Filter, 2021). In combination with a classic nose clip, it guarantees effective sealing. It is used mainly in a high concentration of respirable specks of dust, welding, and soldering. It protects against dust containing beryllium, antimony, arsenic, cadmium, cobalt, nickel, etc. radium, strychnine, and radioactive particles. In addition, it uses an exhalation valve, which allows for the free removal of excess water vapor and carbon dioxide from under the half-mask cup, thus improving the user's work comfort and extending its life. The composition of the half-mask is a needle-punched polyester non-woven fabric, a melt-blown polypropylene non-woven fabric, and a protective non-woven fabric. Additional elements include an exhalation valve, a nose clip for sealing the half-mask in the nose area, a nose seal made of polyethylene foam, buckles for the headband to adjust, and headband.

The selection of respiratory protection equipment for biological hazards is described in the publication (Majchrzycka and Okrasa, 2019). Minimizing the harmful effects of biological factors on humans depends on the extent to which employers fulfill their obligations under Directive 2000/54 / EEC / the Regulation of the Minister of Health on the protection of employees against biological agents.


Fig. 2a. Operator in a protective suit (own source)


Fig. 2b. Filtering half mask (source: Filter, 2021)


Fig.2c. Surgical cap (own source)


Fig. 2d. Protective overlays for footwear (own source)


Fig. 2e. Face shield, operator helmet (own source)

Sterile gloves (Skamex, 2021) manufactured by Sempermed (SEM-8227515) are latex, powder-free surgical gloves with an internal polymer layer with a physical web structure. The slightly reduced thickness of the latex layer provides a great feeling necessary for the operator of the devices. The patented inner layer makes it easy to apply the glove to a dry and damp hand. Also, putting the glove on the gloves is not a problem. Thorough rinsing during production results in the lowest level of latex proteins, which, combined with the barrier constituted by the synthetic layer, effectively prevents latex allergy symptoms.

A surgical cap (Emercator, 2021) is made of non-woven fabric with an elastic band for universal use (Figure 2c). Cap is made of airy spun-bond non-woven, forage type, with an elastic band at the back and having a longer front part that allows the cuff to be turned up.

Other elements of the operators' protection are the overlays for footwear shown in Figure 2d and the face shield presented in Figure 2e.

The face shield is a universal helmet (Reis, 2021) consisting of an anti-spatter polycarbonate lens, headgear, and hinge assembly (REIS, OTY Y EAN: 5907522910198). Dimensions: height 203 mm, width 394 mm, thickness 1 mm ensure appropriate positioning of the lens to the face ensuring the possibility of adjusting the head harness to the head circumference, providing protection against liquid splashes, protects against minor splashes of solid bodies with an impact energy of up to 120 m/s (B), meets the requirements of EN166. The product used in industries such as mechanics and operators of machines and devices, construction works (assembly and installation), heavy industry (including serious construction works), agriculture and gardening, has also become an element of personal protection during the COVID-19 pandemic.

The employer recommends the use of disposable underwear. The employee, however, had a choice to use disposable underwear or own underwear (personal clothes). In the case of disposable underwear, an employee complains about the non-functionality of this disposable medical underwear. During work, due to excessive sweating, the underwear sticks to the body.

## 6. Thermal imaging of an operator wearing disposable personal protective equipment

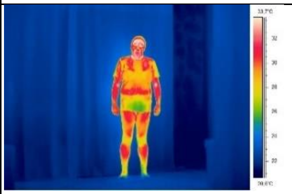
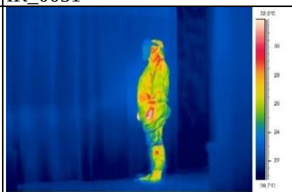
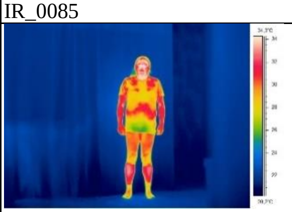
The visual inspection by thermal imaging of the employee was performed with the Flir SC 660 thermal imaging camera. The camera was placed on a tripod at the height of 1.2 m and 7 m from the object. The study was conducted in a break room. Table 2 presents the employee's thermograms. The thermograms were made in the automatic mode of the camera operation, assuming the emissivity of 0.95 and the rain900 color palette. The composition of thermograms presented in Tables 2 and 3 is purposeful. The publication (Stypułkowski et al., 2021) proposes an algorithm implemented in the IT system to support security management using image analysis, including a thermal image. This solution can also be used to monitor the work of an employee wearing personal protective equipment. The IT tool for monitoring railway infrastructure elements based on thermal image analysis and machine learning is universal. It only requires adaptation, the aspect of which is the collection of an appropriate number of thermograms needed to learn the system. This way, the characteristics of an operator's body working with and without a protective suit are extracted from the thermal image.

The image processed and analyzed in real-time will alert operators about possible anomalies and threats resulting from, e.g., overheating the body. For this purpose, thermograms made in the automatic mode of the camera operation are used, emissivity 0,95, humidity 50%, and the composition of the image in which the human body is presented in three insertions; front, profile, and rear.

Table 3 presents a list of thermograms for which they were processed using the specialized software of the camera manufacturer for the analysis and interpretation of thermograms. The medical color palette was used, the temperature range was corrected for these thermograms from 20 to 40 °C, emissivity 0.95, and a distance of 7 m, without changes.

The medical color palette introduced in Table 3 facilitates the interpretation of thermograms by people with medical experience. The medical color palette is commonly used in medicine. This is particularly important in the expert analysis module, which allows analyzing data related to the tested object while determining the input parameters presented in (Stypułkowski et al., 2021) and adapted to assess selected aspects of thermal comfort of an employee working in a personal protection suit. Temperatures ranging from 20 to 40 ºC presented in Table 3 ensure quick identification of characteristic features of the image. These features may indicate that the permissible temperature for thermal comfort values is exceeded.

Table 2**.** Summary of thermograms of the operator's body for the individual research stages

| | The composition of the thermogram, the view of the object: | | |
| --- | --- | --- | --- |
| | front | sideways | back |
| Before putting on protective clothing and before starting work |  IR_0048 |  IR_0051 |  IR_0054 |
| Wearing protective clothing and before starting work |  IR_0064 |  IR_0066 |  IR_0068 |
| Before taking off the protective clothing after work |  IR_0085 |  IR_0087 |  IR_0089 |
| After taking off the protective clothing at the end of work |  IR_0090 |  IR_0093 |  IR_0094 |

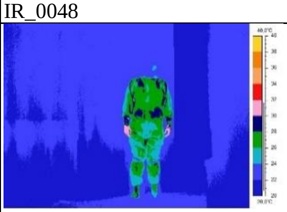
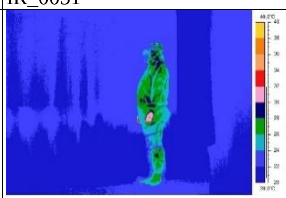
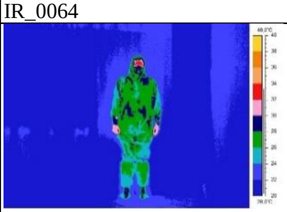
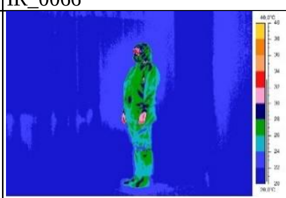
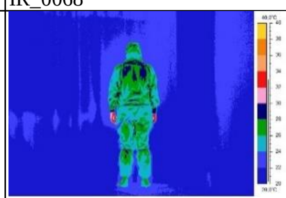
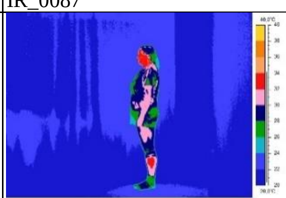
The challenge for the algorithm used in the study (Stypułkowski et al., 2021) is to identify the characteristic features indicating uncomfortable working conditions in disposable personal protective equipment. The summary of these thermograms is presented in Table 2 and Table 3 for two cases. In the first line described as; after putting on a protective suit, before starting work, thermograms numbered: IR_0064, IR_0066, and IR_0068. In the second, before taking off the protective clothing after finishing work, there are thermograms with the numbers: IR_0085, IR_0087, and IR_0089. Thermograms with a visor on for the first case were chosen deliberately. The face is invisible and without a protective bill for the second with the employee's face visible.

Due to the free movement and the risk of mechanical damage to the protective suit, the employees decide to use the oversized suit. In this case, which is also visible on the presented thermograms, an air chamber of various volumes is created between the employee's body, adjacent underwear and clothing, such as a loose T-shirt and tight leggings, and a protective suit. Thermograms using the medical color palette present the transforming areas on the suit's surface with the temperature from 24 to 26 °C marked in light blue and the areas corresponding to the temperature from 26 to 28 °C kept in green. The dark blue regions from 28 to 30 °C are where the suit clings to the personal clothing. At this stage, the hands with the protective gloves are where the read

temperature is close to the body temperature. The colors used in thermograms correspond to temperatures from 30 to 32 °C. Pink and red colors correspond to the temperature from 32 to 34 °C. It is customary for an employee to put on two pairs of gloves. The second pair is changed depending on the wear and tear and each time after operations requiring sterility.
Figures 3 and 4 show thermograms of the operator's body. The medical color palette used for these thermograms and the applied IT tools, such as the area and isotherm, facilitate assessing the employee's physical condition due to thermal comfort.

To eliminate the effect of the thermal radiation background, a correction of the temperature span from 23 °C to 38 °C was adopted in Figures 6 and 7. Thus, the homogeneous background effect for the thermograms is obtained. The critical factor in assessing thermal comfort is the use of the isotherm tool. A person with medical knowledge can clearly determine whether the proper temperatures for the human body are exceeded or not, and the effects of thermal discomfort are observed.

Table 3. Summary of thermograms of the operator's body for the medical color pallet

| | The composition of the thermogram, the view of the object: | | |
|---|---|---|---|
| | front | front | front |
| Before putting on protective clothing and before starting work |  IR_0048 |  IR_0051 |  IR_0054 |
| Wearing protective clothing and before starting work |  IR_0064 |  IR_0066 |  IR_0068 |
| Before taking off the protective clothing after work |  IR_0085 |  IR_0087 |  IR_0089 |
| After taking off the protective clothing at the end of work |  IR_0090 |  IR_0093 |  IR_094 |

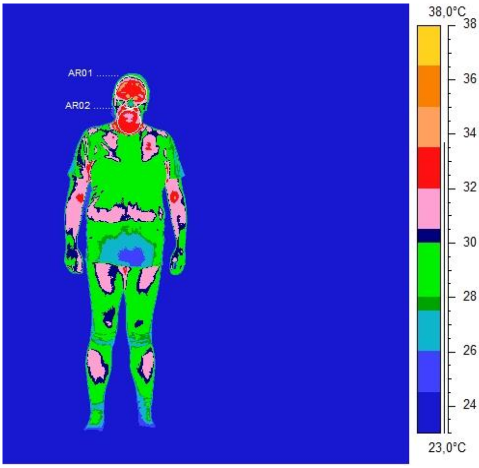



Fig. 3. IR_0048 thermogram, color palette medical, span correction from 23°C to 38°C, isotherm tool used - green color temperature range from 28 °C to 30 °C, before putting on a protective suit, front view

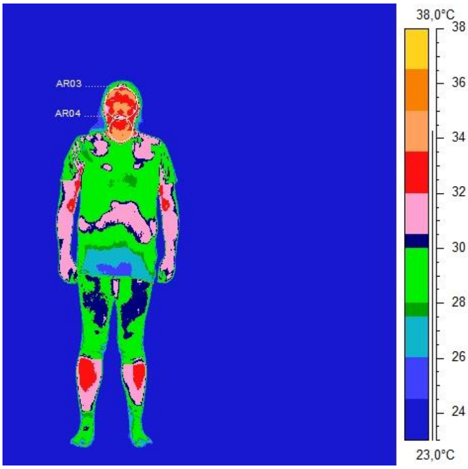



Fig. 4. Thermogram IR_0090 in medical color palette, span correction from 23 °C to 38 °C, isothermal tool used – green color marks temperatures from 28 °C to 30 °C after taking off the protective suit front view

The worker shown in Figure 3 is dressed in personal underwear, a loose cotton T-shirt, women's 100% cotton, 3/4 women's leggings, 94% cotton, 6% elastane, the composition of the clothing as declared by the manufacturer. The average maximum temperature for the AR01 area is 34.6 °C, in the AR02 area is 33,7 °C with an emissivity of 0,95. After correcting the emissivity to 0,98 for human skin, temperatures for the area AR01 is 34,2 °C, and for AR02 is 33,3 °C. The area marked in green corresponds to the temperature on the surface of the garment from 28 to 30 °C.

The main difference between the thermograms presented in Figures 3 (thermogram IR_0048) and 4 (thermogram IR_0090) is that the employee whose thermogram is shown in Figure 4 is sweaty after the end of the three-hour duty. The IR_0090 thermogram presented in Figure 7 shows the body's physical reaction after working for three hours in disposable PPE.

After taking off the protective suit, the employee stays sweaty, but the body efficiently and adequately removes the excess heat. Due to excessive body sweating during activities, the maximum working time was assumed to be 3 hours. After a three-hour cycle, the employee has an hour break, during which he rests, has the option of replenishing electrolytes, can eat a regenerative meal.

The average maximum temperature for the AR03 area is 35,2 °C, in the AR04 area – 34,3 °C with an emissivity of 0,95. However, after correcting the emissivity coefficient to the value of 0,98 for human skin, these temperatures are respectively for AR03 – 34,8 °C and AR04 – 33,9 °C.

The differences between exposed areas, such as limbs and face, indicate higher body temperature. In the face, the temperature of 34,6 °C (area of AR01) increased to 35,2 °C (area of AR03) for the sweat-covered skin.

Analyzing the areas of the lower limbs and their exposed parts, an increase in body temperature is visible after taking off personal protective clothing. For the thermogram presented in Figure 6, we observe temperatures from 28 to 30 °C - green, corresponding to the adopted temperature range for the isotherm. Subsequent temperature ranges from 30 to 30,5 °C - navy blue color and temperatures from 30,5 to 32 °C - pink. For the thermogram presented in Figure 7, we observe increases in these temperatures despite a sweaty body. These temperatures are respectively from 30,5 to 32 °C pink and from 32 to 33,5 °C. In both cases, the emission factor was 0,95.

## 7. Conclusions and recommendations

Thermal imaging cameras are becoming more common in a variety of applications. According to the authors, it is possible to use a tool such as a thermal imaging camera combined with a properly designed software - IT system (Stypułkowski et al., 2021) for the observation, monitoring the physical condition of an employee, and detecting irregularities and threats. This is especially important when an employee works in a restricted area or other isolated area or room. The employee is exposed not only to the risk of infection with the SARS-CoV-2 virus, which is associated with stress during maintenance and which is also intensified by the physiological reactions of the body resulting from working in protective clothing.

At this stage of work, it was decided to carry out tests of thermovision inspections for one person wearing a popular protective clothing set available in the workplace in order to develop a research procedure for future cases.

The employee, the operator, has not worked in a protective suit before. The interview clearly shows that the first hours and days in protective clothing cause great psychophysical discomfort. The operator used the term "tragedy" when assessing the feelings about using this setup. The operator reported breathing problems, thermal discomfort, and excessive sweating. Based on the interview and conversations with employees, it was noticed that after the acclimatization period, especially younger staff work effectively for up to 12 hours in a 3 x 3-hour cycle with hourly breaks. While younger operators "feel good in it", older staff members prefer an 8-hour duty shift with a 2 x 3-hour cycle in protective clothing in a COVID ward.

Such feelings are typical for employees working for more than 3 hours in protective clothing, whose work does not require prolonged sitting and full concentration. The situation is different in the case of professional drivers, especially medical ambulances, special vehicles for the transport of infected persons, and public transport drivers. Public transport drivers are a group of employees particularly exposed to pathogen contamination due to the nature of their work. The pandemic situation in 2019-2021 required the protection of these workers against contamination; however, no protective clothing measures were necessary. If the condition worsens or a new pathogen appears in the future, it may also be required to wear full protective clothing for non-medical workers.

The work of vehicle drivers, with some exceptions, is governed by national regulations on drivers' working and rest times. It is postulated to implement supplementary provisions, considering the possibility of working in a protective suit and the resulting difficulties. These difficulties can affect transportation safety by distracting the worker, weakening the body, and frustrating discomfort. It is necessary to conduct specialized research in this area.

Another area of application of the proposed tests is the automatic detection of the limited discomfort of operators/drivers through constant monitoring in the real-time or periodic measurement of the temperature distribution of the body of an employee wearing protective clothing. Recognizing the overheating symptoms can be entrusted to a person with medical education or artificial intelligence mechanisms in the future.

Additional conditions affecting the ergonomics of work presented in this article should be taken into account in new systems in the field of intelligent mobility and smart city and in planning supply chains implemented in exceptional cases.

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