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Numerical and Experimental Study on Personal Protective Equipment Suit Cooling in the COVID-19 Pandemic with Thermoelectric Module

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Abstract

The staff must wear personal protective equipment (PPE) to prevent infection while treating and managing severe acute respiratory syndrome Coronavirus-2 that causes COVID-19. The use of PPE is expected to increase in the industrial sector, including a mask/respirator. Wearing PPE and accessories causes discomfort to the staff due to the heat, which results in the body being stressed while working. Reducing stress due to work heat can help extend working time, help make decisions, and help stop the spread of COVID-19. The heat generated by the human skin is in the form of heat energy. The application of a thermoelectric cooling module for cold air circulation and human skin cooling while PPE wearing has been analyzed. Three different cold air-supplied positions have been considered for the PPE suit's cooling capability and air temperature distribution. It is found that the average temperatures of the human skin are 22.5 °C, 22.9 °C, and 23.8 °C, for the TECOB, TECON, and TECOL, respectively. The results and innovation obtained can be used to reduce thermal stress from wearing a PPE suit for prolonged working time and decision improvement.

Keywords: Air circulation; PPE suit; Thermoelectric cooling module; COVID-19 Pandemic.
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1. Introduction

In the current situation with the spread of the coronavirus, virus-2019 affects the population's daily life. It also causes problems for the world economy, causing trade to shut down. Eating fast food causes diabetes, high blood pressure, *etc*. In modern society, most people focus on living as a single family and do not want to have a breeding obligation, causing the population to decrease. As a result, it has become a society where the proportion of older people or the population aged 60 years or more is constantly increasing. While the proportion of the birth rate and the number of the working-age population is declining. The proportion of older people tends to increase of 20-30 percent in 2021, indicating that 100 have 30 older people. Various health problems and chronic diseases follow this, so most people must deal with older people's health issues. At present, treating patients, whether they are normal patients or patients from the spread of the virus. Hospitals must have modern treatment equipment. Recording and processing still require the operator to use the equipment to measure the patient, record the results, and send the patient's measurement report to the physician, which takes a long time to know the patient's condition—causing the staff to be unable take care of the patient immediately, resulting in decreased performance. At present, the Internet of Things system is a technology that can connect various devices by using the Internet network to communicate and link information between each other. The IoT system has been used in various applications, including transportation, education, industry, and medicine. The design of the personal protective equipment (PPE) suit is not ventilated, which results in staff having a high perspiration rate

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and fatigue even on non-hot days.[1] The relationship between wearing PPE and occupational thermal stress is still present. During exercise, the generated heat is continuously produced by the metabolism. The principle of metabolic cooling is air circulation circulating through the human skin.[2] Therefore, there is a need for cooling the PPE suits while working for staff during the COVID-19 outbreak. PPE suits are completely encapsulated, making movement difficult and impeding heat transfer from the body. Therefore, when staff wears PPE for a long time, work hard, and work in high-temperature environments causes heat to accumulate in the body[1]—the limited cooling of the body results in rapid fatigue. According to research, higher adverse health effects increase as the body works under overheating conditions[3] and dehydration,[4,5] which affects decision-making while working.[6,7] Therefore, the body requires frequent breaks, affecting performance.[8] If the body cannot maintain an average temperature (37 °C), it may lead to physical discomfort or illness such as fatigue, cramps, heat stroke, or even death. By reducing thermal stress while working, working time can be reduced, decisions can be improved, and the spread of COVID-19 can be prevented.[9] Considering several literatures, body skin temperature was not the same at different locations. Table 1 illustrates the average skin temperature at various positions,[10-12] similar to those reported by.[13,14] According to the data, a low-temperature environment produces the most healthful situations. A skin temperature increase of 4 °C is caused by a 10 °C increase in ambient air temperature.

The thermoelectric generators at the arms and legs can measure thermal energy while sitting, walking, jogging, and cycling. The power produced is between 5 and 50 W/cm^2.[15] The heat released by the body has been used to monitor the metabolic rate. While resting, the released heat is 3.8 μW/cm^2 or 77 μW/cm^2 of physical activity.[16] The heat generated is about 20-50 μW/cm^2 at a temperature of 28 °C.[17,18] In addition, the heat released by younger people (42 μW/cm^2) is greater than that of older people (35 μW/cm^2).[19] There are many ways to reduce heat from wearing PPE, including controlling the work environment, adapting to hot working environments, drinking water and minerals, adjusting work/rest schedules (to have longer breaks), *etc*. However, adjusting the work schedule/more extended rest periods is impossible in a medical facility. This is due to insufficient staff during the COVID-19 outbreak. In addition, the WHO and ILO recommend that workers at risk of heat stress be monitored for symptoms, check the color and quantity of urine, limit the amount of time wearing full PPE, and provide a cool accommodation area with adequate clean, safe drinking water. The risks of thermal stress have been addressed by addressing several regulatory deficiencies. PPE's lack of comfort can worsen heat stress's impact.[20] The main objective of PPE is to protect employees against chemical, biological, thermal, and mechanical hazards. A variety of polymers are currently used to manufacture PPE.[21] For example, the gloves can be produced using polymers, high-performance polyethylene, polymer or polymer coated, single- or multi-layer.[22–25] Various synthetic materials can also manufacture protective clothing according to the required protection. Meta-aramide, polybenzimidazole, polyphenylene benzobisoxazole, and polyimide are employed in heat or flame cases. Polyurethane and polyvinylidene chloride can achieve waterproof coatings and moisture barriers.[24,26] Chemical protection is achieved by using activated carbon-impregnated foam, fluoropolymer, nonporous polyurethane membranes, or elastomers.[27]

Dissipating heat from the human body involves heat conduction, heat convection, heat radiation, and evaporation. Numerous cooling techniques have been developed to improve human thermal comfort and temperature control in indoor and outdoor hot environments. Devices that can be classified include air-cooled, liquid-cooled, and thermoelectric. Numerous researchers have been involved in research on air-cooled garments. The cooling system with pressurized CO$_2$ was utilized by[28] to cool garments and reduce humidity sensation, resulting in enhanced personal comfort. Hadid *et al*.[29] and Zhao *et al*.[30] considered the effect of an air-cooling system on the physiological strain of the human body. Next, a hybrid cooling of garments for personal cooling has been investigated,[31-33] and the results showed significant improvements in thermal regulation. The discovery was that air-cooled garments can remove heat of more than 101W. Barwood *et al*.[34] and Webster *et al*.[35] considered the cooling capability of air-cooled garments. The results showed that the ventilated vest provided enough cooling and reduced thermal strain during prolonged.

Table 1. Average human skin temperature readings at various locations.

Body Positions	(Yang *et al*., 2011) (T_{air} = 17 ºC)	(Zaproudina *et al*., 2008) (T_{air} = 23.5 ºC)	(Webb *et al*., 1992) (T_{air} = 27 ºC)
Forehead	29.5	34.1	35.2
Neck	31.1	33.2	35.1
Back	30.6	32.5	34.4
Chest	30.3	32.3	34.4
Arm anterior	30.3	31.7	33.2
Forearm	29.5	31.5	34.0
Thigh	28.3	30.8	33.0
Calf	29.4	31.3	31.6
Foot dorsal	27.1	28.6	30.4

The previous air-cooled systems are severely affected by the low specific heat associated with the air, which leads to a low heat transfer rate. Liquid-cooled systems have been introduced in the past few decades to address the problems with higher heat-flux applications, especially when workers face extremely high temperatures, resulting in thermal discomfort. In the worst cases, heat strain or heat stroke can be caused by personnel working in these conditions.[36] Effective heat and moisture management is crucial for personnel working in harsh environmental conditions. A battery-operated pump circulates the cooled liquid inside the garment tubes. Cooling different body surfaces during upper and lower body exercises has been studied.[37] Comfort can be improved by using a three-layer structure with tubing sandwiched between the inner and outermost layers of fabric. Cooler conditions like tube length, tube type, liquid inlet temperature, ambient conditions, flow rate, and flow pattern have influenced thermal efficiency. The clothing absorbs either direct or indirect heat transfer into the tubing system. The efficiency and effectiveness of different water-cooled suits are considered.[38,39] The surface volume ratio regulates the conduction between the body skin and convective liquid.[40] Yuan *et al*.[41] provided the fundamental details for developing high performance. Using a cooling vest resulted in a skin temperature decrease of 1.2–2.5 °C.

Recently, for the thermoelectric cooling module, Xu *et al*.[42] used thermoelectric refrigeration to circulate liquid for the man-portable cooling garment to avoid life-threatening situations. Several performance tests were conducted in a simulated hot environment to evaluate and optimize refrigeration efficiency and cooling effectiveness. A new type of liquid cooling garment prototype based on thermoelectric cooling modules has been proposed to prevent humans from heat injury and achieve global energy savings.[43-45] Next, Lou *et al.*[46] considered the wearable cooling and dehumidifying system for personal protective equipment. Wang and Zhao[47] studied the three liquid–air hybrid cooling garments and one control garment was designed. Son[48] studied the cooling performance of the Peltier cooler with a blower motor for protective clothing. Dabrowska *et al.*[49] evaluated the performance and power consumption of a thermoelectric module-based personal cooling system to reduce workers' thermal discomfort during their routine professional activities. Li *et al*.[50] simulated the performance of portable semiconductor refrigeration devices for human body cooling. Zhao *et al*.[51] and Zhang *et al*.[52] developed air ventilation garments with small fan panels to improve thermal comfort and relieve the thermal stress of the body in hot environments. As indicated above, many articles have presented the areas of thermoelectrical application, especially for garment cooling. However, only one[46] considered a thermoelectric air-cooling module to reduce the thermal stress of the medical staff with PPE. Furthermore, air-cooling systems have numerous advantages, which include a simple system, less weight, inexpensiveness, and less energy consumption. Due to the limitations of air properties, the cooling system is unsuitable for extremely high temperatures and humidity. A cooling system can be developed using a thermoelectric cooling module to achieve higher thermal performance. This paper examines thermal cooling and human skin temperature wearing PPE with a thermoelectric air-cooling module. Three different cold air-supplied positions have been considered for the PPE suit's cooling capability and air temperature distribution. The predicted results from the numerical analysis have been verified with the measured and published data.

2. Methodology

2.1 System description figure

Figure 1 shows the model with a combination of PPE and a thermo-electric cooling unit. The thermoelectric cooling module is installed at the back of the PPE suit, in which the cold side is inside the PPE suit while the hot side is outside the PPE suit, as shown in Fig. 1. This means that the circulation of cold air flow inside the PPE suit is the air circulation in the closed vessel. The participant wears PPE to treat patients suspected to be infected with COVID-19. The thermoelectric cooling module (TCM) comprises four axial fans, three heatsinks, and two thermoelectric plates. A special high thermal conductivity adhesive fastens both sides of the Peltier plate to the heat sink. The Peltier plate is capable of cooling at 60W and operating at 70 °C. Twenty-eight T-type thermocouples are used to measure the air temperature, which is pre-calibrated with a dry-box temperature calibrator, as illustrated in Fig. 2, connected to the PC.

2.2 Experimental procedure and uncertainty analysis

To against the spread of COVID-19 into the cooling system, the cold air circulation of the thermoelectric cooling unit system is designed as a closed circulation system, as shown in Fig. 1. The study was conducted under constant regular room temperature (25 °C± 0.5 °C). The study consisted of two cycles performed within two days. The first PPE test explored the effects of PPE without a thermoelectric cooling unit with different activities. The second one, the cooling test, examined the impact of PPE with a thermoelectric cooling unit with different activities. The dimensions of the PPE suit are listed in Fig. 3. Three different supplied cold air positions (constant air flow rate) have been done, as shown in Fig. 4, which is measured by the portable anemometer. The temperature reading accuracy is ±0.2% of the full scale.

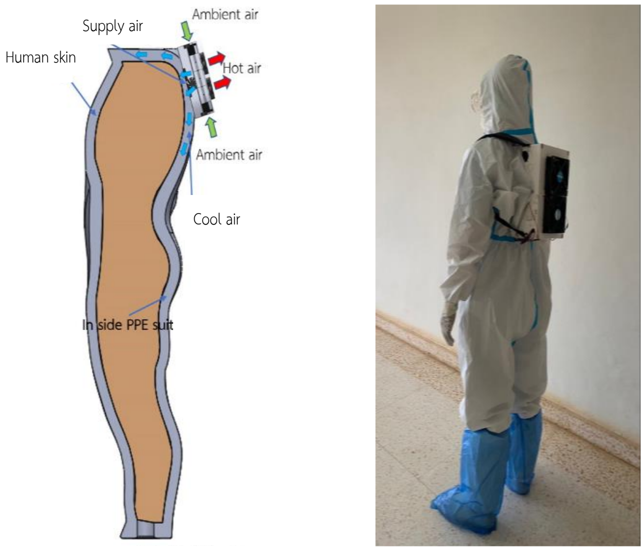


Fig. 1 shows the photograph of the model with a PPE.

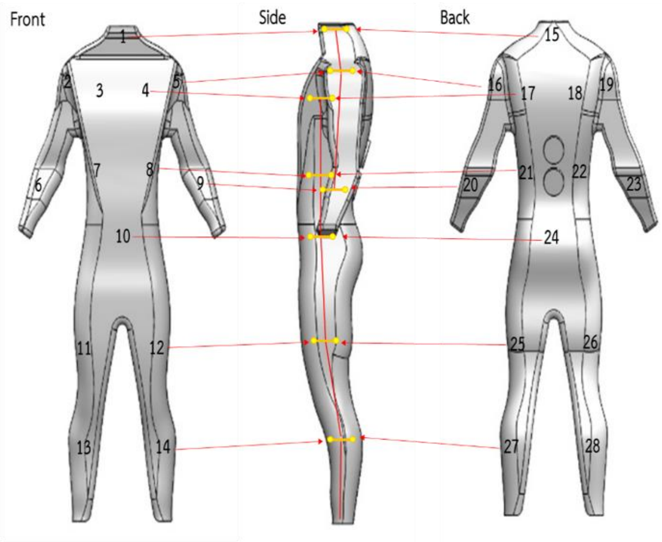


Fig. 2 The positions of the temperature measurement of the model with a PPE suit.

3. Mathematical modeling

3.1 Geometrical models

To numerically analyze the cooling characteristics of the PPE suit, a mathematical model of thermal and airflow circulation through the gap between the human skin and the PPE suit is developed with three dimensional, as shown in Fig. 3. The considered model with three different air-inlet positions is shown in Fig. 4. However, the air-inlet from outside is assumed to be the two cold plates inside the PPE suit, and set initial airflow velocity. To deal with this, the air gap inside the PPE suit is divided into many segments. There is no heat exchange between the outside PPE suit and the environment. The heat transfer process between the human skin and the air inside the PPE suit is assumed to be uniformly distributed throughout the human skin with the assumptions as follows:

- Single-phase steady-state 3D flow situation is turbulent.
- The air gap is assumed to be a constant value.
- Adiabatic boundary conditions over the external surface.
- The variations of the thermophysical properties of air inside the PPE are excluded.
- Gravitational forces and constant airflow properties are considered
- Radiation and convective heat transfer are excluded.
- Contact resistance (PPE suit and air) is excluded.

3.2 Main governing equations

The governing equations of the problem are presented as follows:[53-55]

$$\frac{\partial \rho \bar{u}_i}{\partial x_i} = 0 \qquad (1)$$

$$\rho \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu_t\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \rho \bar{u}_i \bar{u}_j\right) \qquad (2)$$

$$\rho \bar{u}_j \frac{\partial \bar{T}}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\left(\frac{\mu_l}{\sigma_l} + \frac{\mu_t}{\sigma_t}\right)\frac{\partial \bar{T}}{\partial x_j}\right) \qquad (3)$$

Turbulence model:

$$\rho \bar{u}_j \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \mu_t\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\frac{\partial \bar{u}_i}{\partial x_j} - \rho\varepsilon \quad (4)$$

$$\partial \bar{u}_j \frac{\partial \varepsilon}{\partial x_j} =$$

$$\frac{\partial}{\partial x_j}\left[\left(\mu_l + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + C_1 \mu_t \frac{\varepsilon}{k}\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\frac{\partial \bar{u}_i}{\partial x_j} - C_2 \rho \frac{\varepsilon^2}{k} \qquad (5)$$

Where:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \qquad (6)$$

$C_1 = 1.44$, $C_2 = 1.92$, $C_\mu = 0.09$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$ (7)

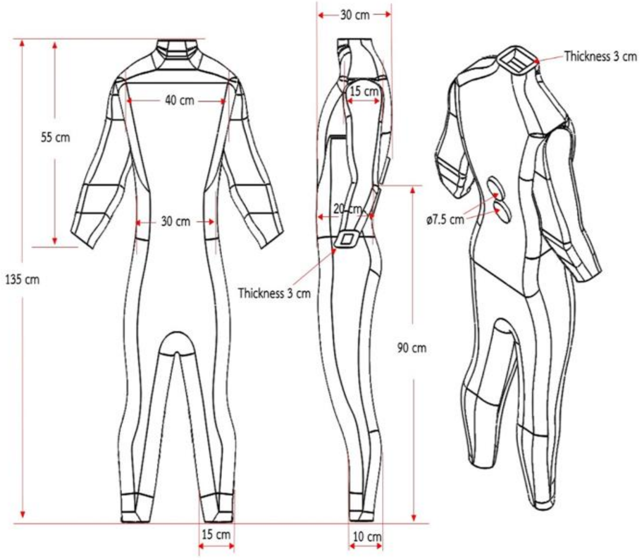


Fig. 3 The dimension of the model used in the numerical analysis.

3.3 Boundary condition

Wall of the heat source and the surrounding wall surfaces:

$$\bar{T} = \bar{T}_{wall} \quad \text{(As shown in Table 1)} \qquad (8)$$

The cold plate inside the PPE suit:

$$\bar{T} = \bar{T}_{in}, \bar{u} = \bar{u}_{in} \qquad (9)$$

PPE suit outer wall:

$$\text{Adiabatic wall} \qquad (10)$$

Human body:

$$\bar{q} = \bar{q}_{in} \qquad (11)$$

Initial closed air flow circulation:

$$\bar{u} = \bar{u}_{in} \qquad (12)$$

3.4 Numerical simulation and verification

In the computational field, as illustrated in Fig. 4, The commercial software (Ansys Fluent) is used as the solver coupling with the SIMPLEC algorithm.[56] The air circulates in the closed jacket vessel with constant heat flux boundary conditions of 20 µW/cm^2.[17] As shown in Fig. 5, the grid configurations of the numerical analysis are depicted in the three approaches to non-uniform processes for grid independence to ensure the accuracy of results. As shown in Fig. 6, the air temperature at the back neck is independent of 9,500,000. The precision of the predicted results is not impacted by the grid number of 9,500,000, which is sufficient for the predicted results to be accurate. 96 GB of RAM and 18

CPU cores are included in the diagnostic computing system. The computation is finished when the remainder reaches the cut-off value ($< 10^{-5}$).

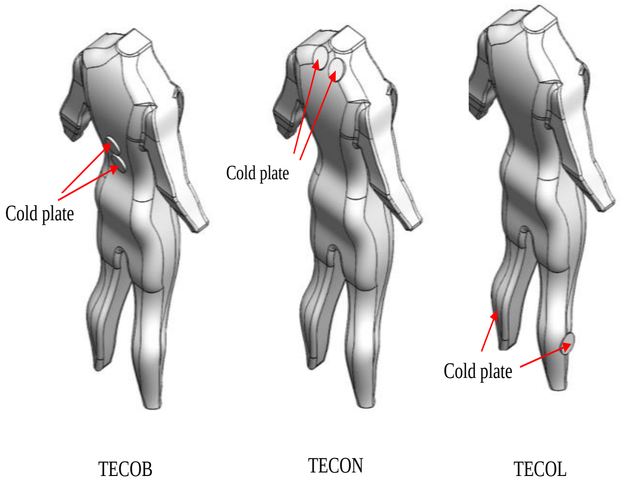


Fig. 4 The three different cold plate positions.

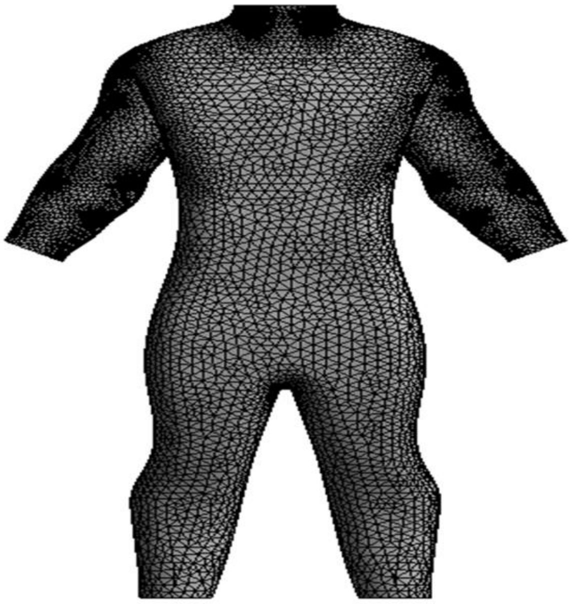


Fig. 5 shows grids of the numerical analysis.

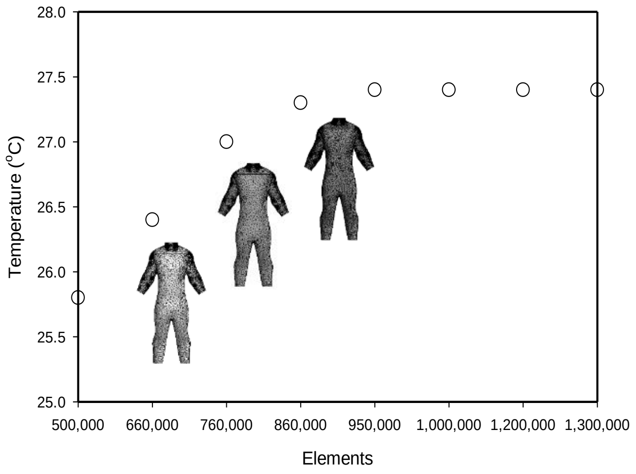


Fig. 6 The grid-independent test.

This section is based on the verification of expected results. To evaluate the flow and thermal behaviors of air circulating inside the PPE suit, the turbulent mixture model is utilized to analyze the flow and thermal behaviors. The PPE suit has not been tested on the thermoelectric cooling unit with different activities, either with or without, as there are no experimental results. As a result, we tried to confirm the intended results by designing the experimental system under similar operating conditions. Because of the symmetrical model, the half-part model temperature distributions are selected to be compared with the predicted results, as shown in Fig. 7. As shown in Fig. 8. the measured data and the results from this study agree and show the maximum and minimum errors of 2.62% and 0.48%, respectively. In addition, the average back temperatures are also compared with the proposed results[10-12] and give average errors of 9.05%, 3.03.87%, and 2.65% as compared with Yang *et al.*[11], Zaproudina *et al.*,[11] and Webb *et al.*,[12] respectively.

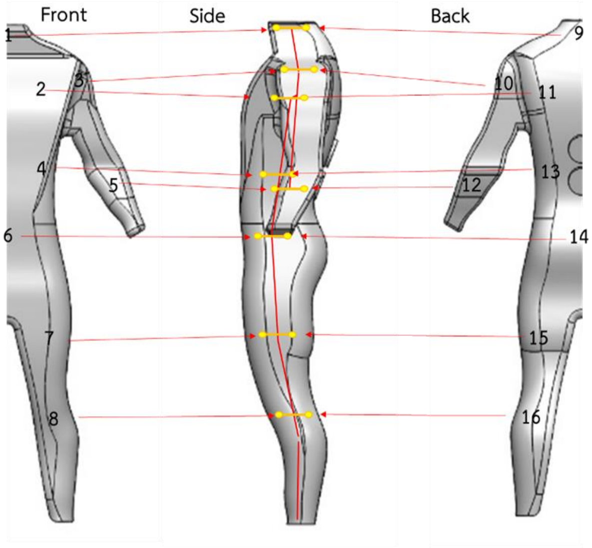


Fig. 7 The temperature positions used in the presentation of the predicted results.

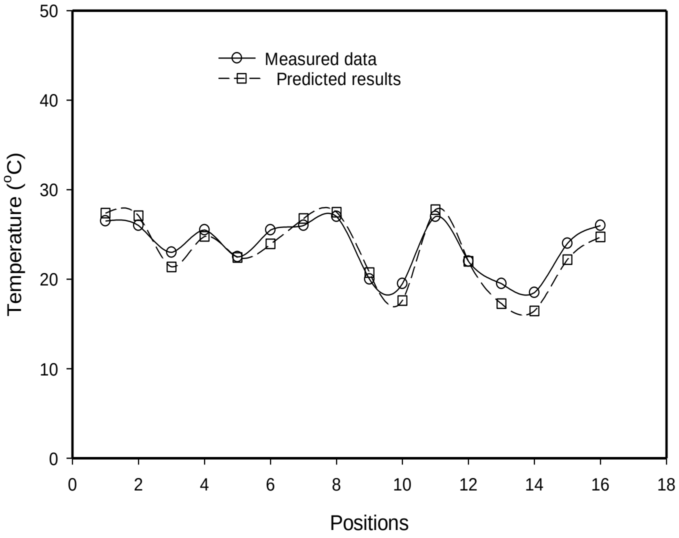


Fig. 8 The temperature comparison between the measured data and the predicted results for the thermoelectric cooling unit (TECON).

4. Results and discussion

Figure 9 shows air temperature variations inside the PPE suit at various locations with and without a thermoelectric cooling system. In the test, the air temperatures inside the PPE suit are measured half an hour after wearing the PPE suit. In the absence of a thermoelectric cooling unit, the heat from the body accumulates by air inside the PPE suit, and then it is in a steady state condition. The air temperature inside the PPE suit at various locations is not equal. The highest and lowest values are 34.2 °C and 33.2 °C at the back body and leg zones, respectively. The supplied cold air position is at the back neck with a constant flow rate and temperature of 15 °C for the thermoelectric cooling unit. The average temperature is about 24.5 °C and is lower than in the absence of a thermoelectric cooling unit, as shown in Fig. 9.

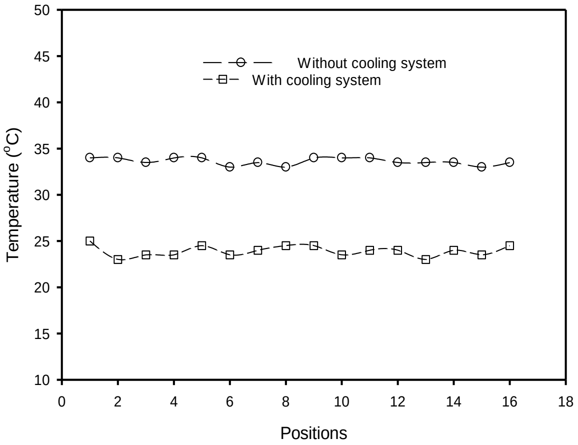
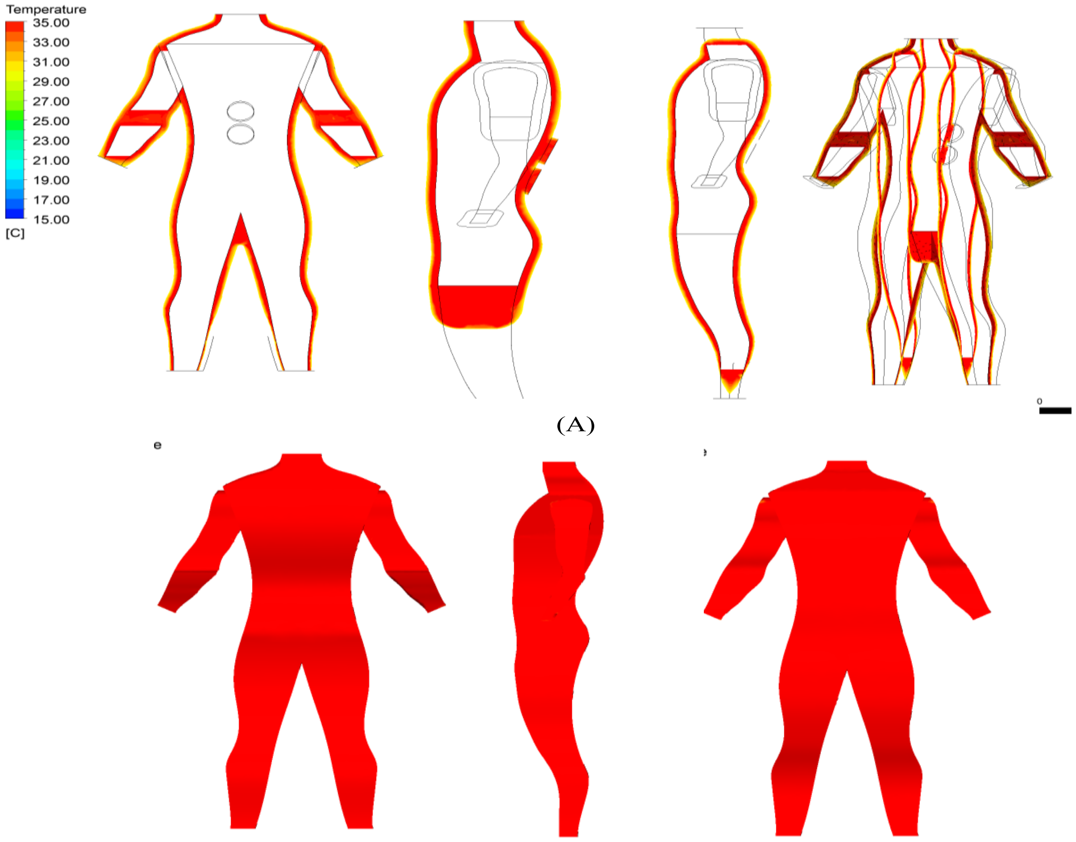


Fig. 9 The temperature distribution of the model with and without the thermoelectric cooling unit.

Figure 10 illustrates the air temperature and the skin variations without the thermoelectric cooling unit. The circulation air inside the closed PPE suit is considered for constant heat generated from the body of 20 μW/cm^2.[17] The main pathways for dissipating heat from the human body are heat conduction, heat convection, heat radiation, and evaporation. The body generates heat continuously through metabolism, which increases during work, during which metabolic cooling is performed when air circulates through the skin.[2] Different thermoregulation physiognomies exist in different parts of the human body, including limbs, feet, hands, head, and torso. Heat transfer is influenced by local heat generation, tissue conductivity, surface area, and other factors. It is implied that cooling requirements for different body parts are not the same. The staff must wear the PPE to prevent infection for a long time. Staying in places with high temperatures makes people feel discomfort and sometimes heat stress during work. According to research, higher adverse health effects increase as the body works under overheating and dehydration conditions.[3-5] affecting decision-making while working.[6,7] Therefore, there is a need for cooling the PPE suits while working for staff during the COVID-19 outbreak. PPE suits are completely encapsulated, making movement difficult and impeding heat transfer from the body. It is found that the generated heat transfers to the air inside the PPE suit and results in increased temperature. The whole air inside the PPE suit and the body, the temperatures at various positions are more than 34 °C. Therefore, the thermal management system for the PPE suit is significant for maintaining temperature in the human comfort zone. The human comfort zone is where the mind expresses satisfaction between 22 °C–27 °C and relative humidity of 40%–60%. However, for a wearable cooling system, the cooling temperature should be above 15 °C to avoid cold pain.

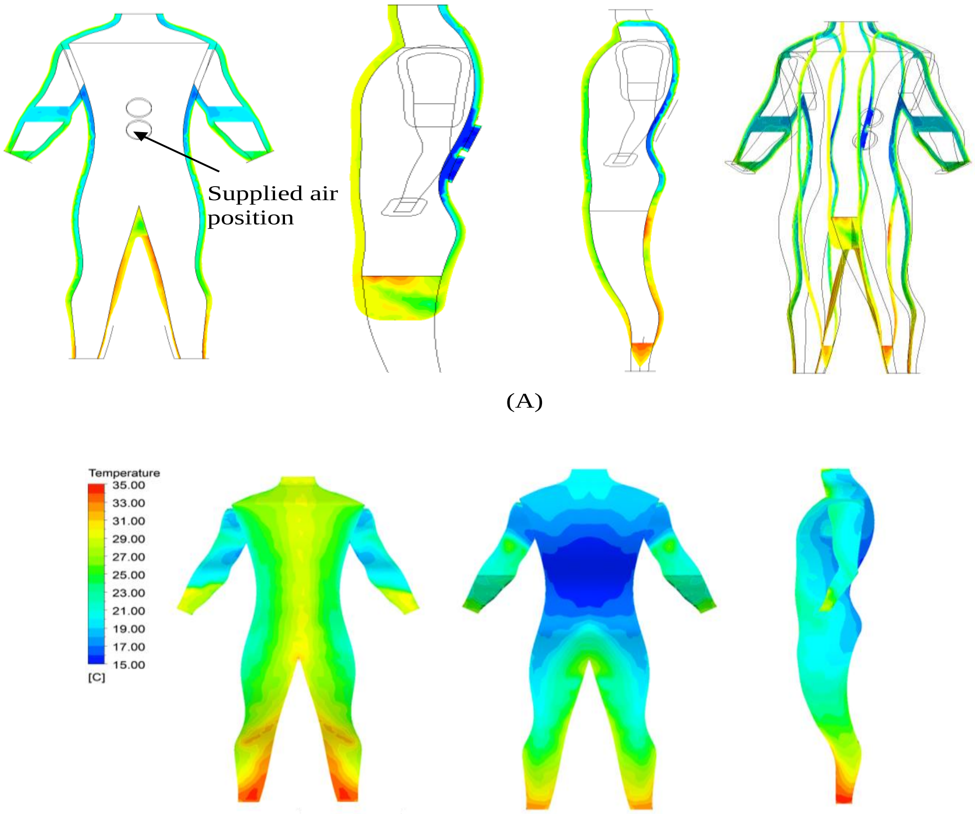
The thermal distribution of air in PPE suits and human skin can be seen in Fig. 11. The flow characteristic is considered by a closed system flow with a cold air source located at the lower back position (TECOB). The cold air velocity at the supply air position is 2 m/s with an initial temperature of 15 °C to flow through the gap between the human skin and the PPE suit, which is constant throughout the suit, equal to 2 cm. The human skin was assigned to be the heat source with a value of 20 μW/cm^2[17] while the outer surface of the PPE suit had no heat loss to the outside air. Convection is the process by which heat is transferred from the human skin to the cold air. After that, when the air has been heated, it will be sucked back into the cooling unit at the back and flow through the cooling system to adjust the temperature to equal the initial condition of 16 °C. It is found that the flow distribution of cold occurs at the upper zone of the body back, which results in the lowest temperature occurring at this zone of 16.5 °C, with a tendency to rise at the arm region of 22.3 °C and the front body of 24.5 °C, respectively. An area zone away from the cooling unit, like the legs, cold air flow does not cover. Therefore, these areas give larger temperatures than other zones, with the highest value at the lower leg at about 26.8 °C, probably because the initial cold air velocity was set to be low in the analysis process. However, the model found that most body areas are mainly low temperatures, giving an overall mean temperature of 22.5 °C. In addition, as the cold air source was changed to the occipital zone (TECON), the characteristics of cold air were concentrated in the occipital area, as shown in Fig. 12. The cold air distribution in the front zone of the body has been determined to be less than the TECOB model. The lowest temperature occurs in the occipital area at 16.5 °C. It increases gradually as the distance to the ventilator increases, and then the maximum temperature occurs at the leg region at 27.5 °C. The average body temperature is 22.9 °C, as shown in Fig. 12. As depicted in Fig. 13, the air supply is moved to both legs. It can be seen that the cold air supply is located on both legs. The temperature reaches a minimum of 18.5 °C and increases as it gets farther from the cooling air source. The temperature was as high as 28.0 °C on both shoulders and 26.5 °C on both arms. This is because cold air flows from the bottom region to the upper zone, and both arms are not completely covered. The majority of body areas have a higher average temperature than the first two types, resulting in an average temperature of 23.8 °C.



(A)

(B)

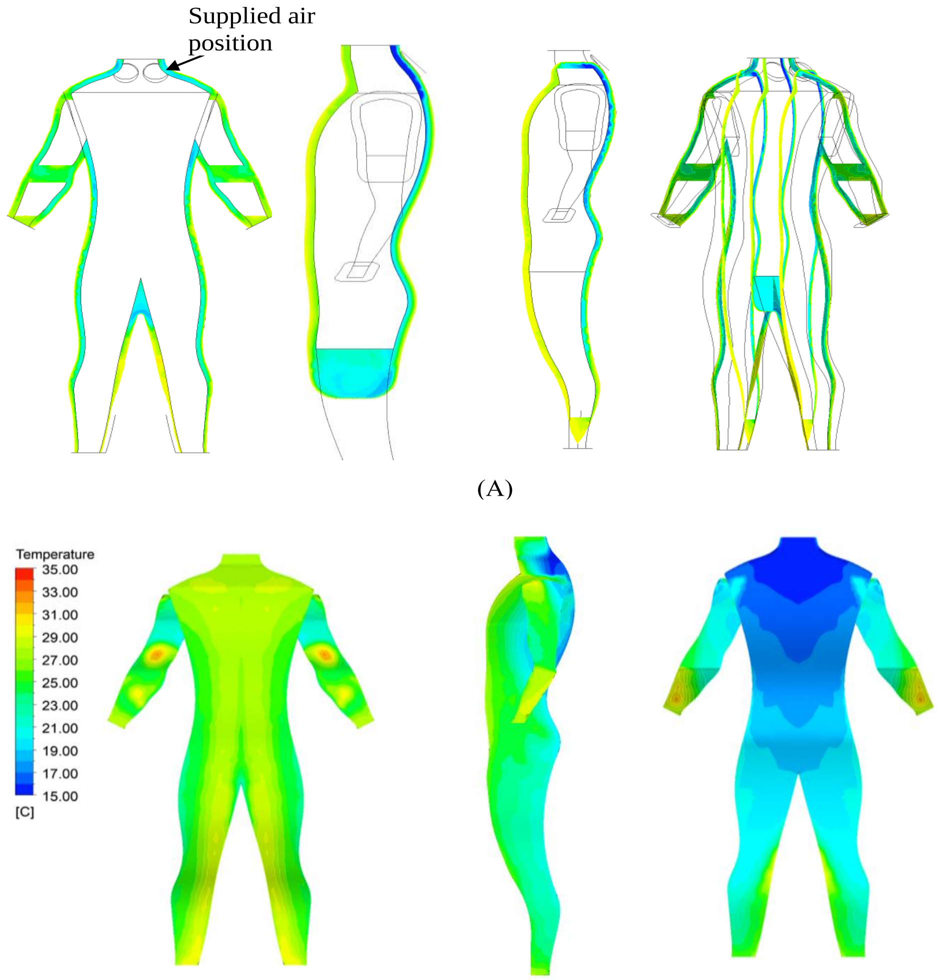
Fig. 10 (A) the air temperature distribution inside the PPE suit and (B) the human skin temperature without a cooling system.



(A)

(B)

Fig. 11 (A) the air temperature distribution inside the PPE suit and (B) the human skin temperature with the cooling system TECOB.



(A)

(B)

Fig. 12 (A) the air temperature distribution inside the PPE suit and (B) the human skin temperature with the cooling system TECON.

The comparison of human skin temperatures across different cold-supplied air positions can be seen in Fig. 14. One can see that the distribution of cold air has an important effect on the cooling and uniform temperature of the human skin. As seen in Fig. 14, different thermoregulation physiognomies exist in different parts of the human body, which are influenced by local heat generation, tissue conductivity, surface area, and other factors. Therefore, the cooling requirements for different body parts are not the same. Maximum and minimum temperatures at different locations occur in different areas. The TECOB's maximum temperatures are found in the leg zone, the front body zone for the TECON, and the upper back body zone for the TECOL. The TECOB and TECON's minimum temperatures can be found in the upper back area and the leg zone for the TECOL. An average human skin temperature from the TECOB is the lowest compared to TECON, and TECOL. This is because most human temperatures are lower than the two models. In addition, weight is an important factor that affects both the convenience of wearable cooling systems and the performance of PPE users.[57] Adding 3–5 kg to clothing weight could raise the metabolic energy cost of wearers by up to 9 – 16 %.[58] A 3.6 kg personal cooling system increases the human's metabolic rate by 11.1 W/m^2.[59] In future studies, the thermoelectric air-cooling module's cooling and dehumidifying effects will be evaluated through human subject tests. The potential of the thermoelectric air-cooling module to extend the safe working duration of PPE users will be investigated.

4. Conclusions

The air circulation and human skin temperature distribution have been presented. The effects of three different air-supplied positions are considered. The air-supplied positions significantly affect the cold air circulation inside the PPE suit, the maximum human skin temperature, and the human skin temperature distribution. The measured data is compared to verify the predicted results, and there is a good agreement. The human skin temperature for the PPE suit with a thermoelectric cooling module is 14.24% lower than without a cooling system. The TECOB model gives the lowest human skin temperature of 22.5 °C, 22.9 °C for the TECON, and 23.8 °C for the TECOL. The highlight of this study is to reduce the burden on medical personnel during the COVID-19 pandemic. The thermoelectric cooling module can be

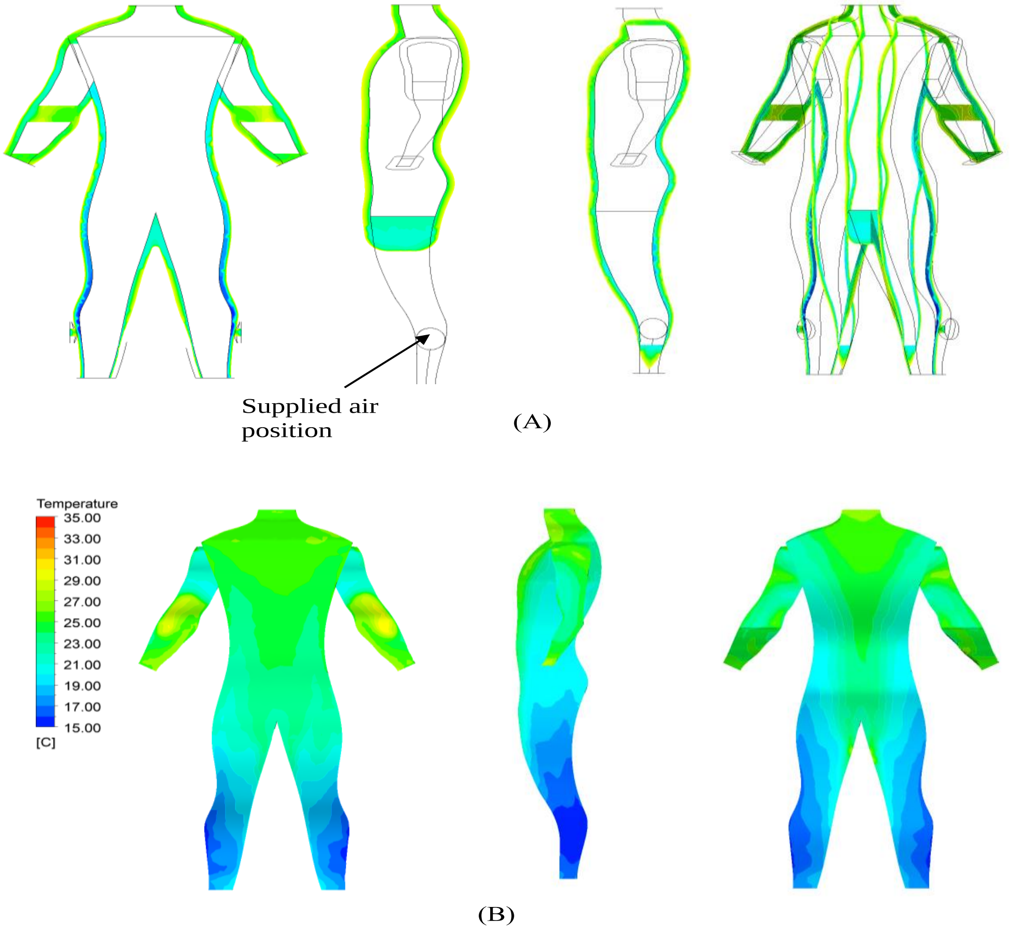


Fig. 13 shows (A) the air temperature distribution inside the PPE suit and (B) the human skin temperature with the cooling system TECOL.

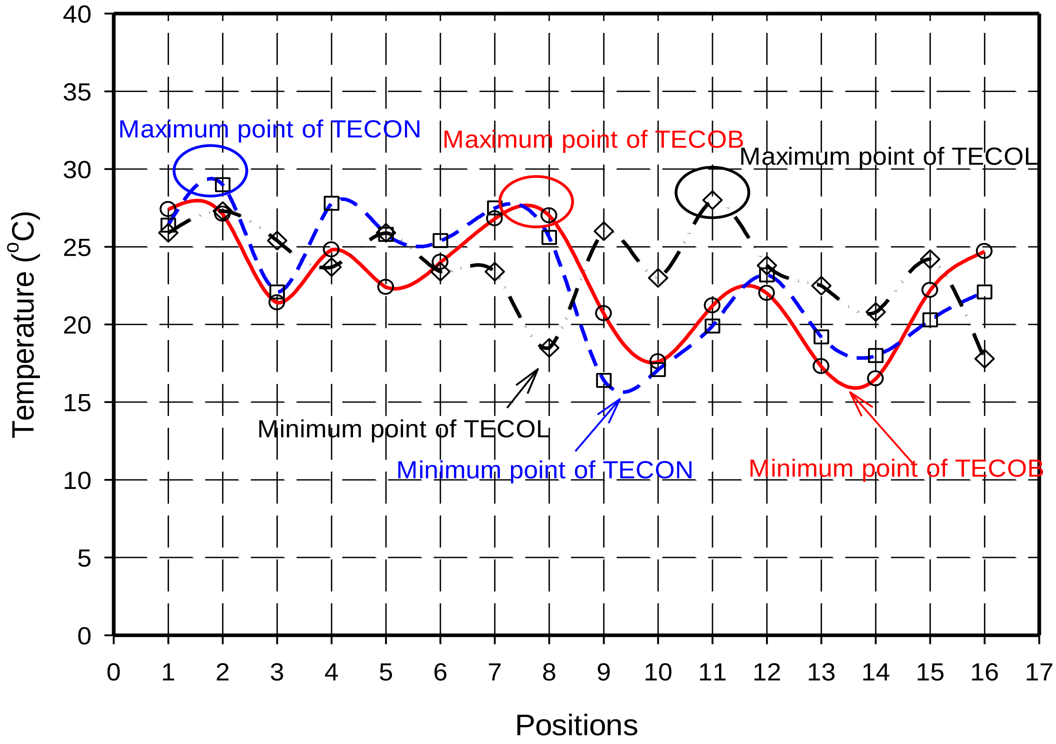


Fig. 14 shows the comparison of temperature distributions from three different air-supplied positions.

advantageous in several ways, including its ability to withstand thermal stress and improve medical care. Based on the results, it can be used as an essential tool to obtain the full potential of this innovation for PPE suit cooling.

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Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

Nomenclature

C1, C2	Closure coefficients for the turbulence equation
k	Turbulence kinetic energy
p	Pressure (kPa)
T	Temperature (K)
u, v, w	Velocity components in transformed plane (m/s)
V_{in}	Inlet velocity (m/s)

Greek symbols

ε	Turbulent energy dissipation rate (m^2/s^3)
ρ	Density (kg/m^3)
μ_l, μ_t	Laminar and turbulent viscosity ($N.s/m^2$)
$\sigma_t, \sigma_t, \sigma_k, \sigma_\varepsilon$	empirical constants in turbulence model equations

Subscripts and superscripts

in	inlet
i, j	indices
wall	wall

Acronyms

PPE	Personal Protective Equipment
TCM	Thermoelectric Cooling Module
TECOB	Thermoelectric Cooling at The Back
TECOL	Thermoelectric Cooling at The Leg
TECON	Thermoelectric Cooling at The Neck
WHO	World Health Organization
ILO	International Labour Organization

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