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Study of the Influence of Different Clothing Materials for Mine Ventilation Clothing on Human Body and Microclimate under Clothing

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Abstract: In order to study the influence of clothing materials on the cooling effect of mine ventilation clothing, the temperatures of human skin and micro-environment under clothing were used as reflection indexes of the cooling effect, and numerical simulations were carried out using fluent software to compare and analyze the temperature changes of human skin and micro-environment under the influence of mine ventilation clothing made of different clothing materials. The results regarding the human skin temperature showed that the modal fiber type resulted in a 0.4 °C lower temperature than the pure cotton type and that the pure cotton type resulted in a 0.6 °C lower temperature than the silica gel type. The temperature comparison of the micro-environment under clothing showed that the modal fiber type resulted in a lower value than the pure cotton type and that the pure cotton type resulted in a lower value than the silicone type; the cooling effect of the three kinds of mine ventilation clothing was modal fiber type > cotton type > silica gel type. In summary, fabric with good permeability and moisture permeability was helpful in improving the cooling effect of mine ventilation clothing.

Keywords: clothing materials; mine ventilation clothing; numerical simulation; cooling effect; sustainable mining

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1. Introduction

As the main energy source, the consumption of coal has been increasing, and the consequent mining of mining resources has reached a deeper level [1,2]. According to relevant information, the internal environmental temperature of a mine changes with the mining depth by 3 °C per 100 m; now, many mines have reached 1000 m and over, and the temperature of the working surface has reached more than 30 °C [3].Coal Mine Safety Regulations [4] require that the air temperature of the working surface of the mine does not exceed 26 °C, and that works are to be stopped immediately when the temperature is higher than the specified one. However, for various reasons, the actual working temperature is usually higher than the 26 °C specified in the regulations, and high-temperature heat damage in coal mines has become another major disaster linked to coal mines [5,6]. Coal-mine high-temperature heat damage is not only harmful to workers but also reduces the work efficiency of workers, and it has a great impact on the economic benefits of enterprises and personal safety; therefore, research on the problem of high-temperature heat damage in mines is of great significance [7–9].

In view of the problem of high-temperature heat damage in coal mines, the current control methods include artificial refrigeration, non-artificial refrigeration, personal protection, etc. Artificial refrigeration and non-artificial refrigeration have their limitations, and in the face of such a situation, social production for individual cooling demand is increasing.

Personal protection technology mainly refers to wearing cooling clothing to achieve the local cooling of the human body, which is very promising for development [10–12].

Mine ventilation clothing is among the cooling suits and is still in the continuous exploration and research stage. Many research results provide a theoretical basis for research on mine ventilation clothing. Yang et al. [13] used fluent software to compare and analyze the temperature field, static pressure field, and velocity field of three different types of cooling suits: direct blowing, air inlet with flow equalizer, and air inlet with a baffle. Chen et al. [14] conducted research through numerical simulation, and the results showed that the temperature distribution of the baffle type was the most uniform, the average flow rate of the direct blowing type was the largest, and the heat dissipation effect was the best. Wang et al. [15] carried out numerical simulations through fluent software, and the results showed that the influence of thermal resistance on the internal temperature of the clothes was small, but the relative humidity in the clothes had a greater impact on the internal moisture resistance of clothing, and the ambient temperature had a great impact on the temperature and humidity under the clothes. Xu [16] explored the influence of a pipeline structure on air-cooled clothing through numerical simulation and found that the longitudinal type of airflow distribution at a low flow rate was the most uniform and that the spiral type of airflow distribution was the most uniform at a high flow rate. Gao et al. [17] completed numerical simulations through Matlab software and found that under the same other conditions, labor intensity had a greater impact on the heat and humidity transfer in the microclimate zone. There are also many studies on clothing materials. Havenith et al. [18,19] drew a human body sweat-wicking map, according to the male sweat map; the configuration of breathable fabrics at the highest sweating rate could increase the role of ventilation and heat dissipation. Zhang et al. [20] discussed the influence of fabric composition on the thermal and wet properties of fabrics through the evaluation of the heat and moisture transport characteristics of fabrics and found that fabric composition had complex effects, which needs further research.

Given this, the authors conducted further research on mine ventilation clothing and the properties of clothing materials. By establishing a three-dimensional physical model to conduct numerical simulation research, the skin temperature and micro-environment temperature changes of the human body under the influence of different types mine ventilation clothing were analyzed, and the cooling effects of mine ventilation clothing made of different clothing materials were compared, which can provide a basis for subsequent research.

2. Ventilation Clothing Cooling Principle

The entire heat transfer and cooling processes are regarded as a system. The human body does not only exist in the surrounding environment but is also in the microclimate of human body–ventilation clothing–external environment, and the microclimate is closely related to the thermal comfort of the human body. Through exercise, the human body accelerates metabolism and generates heat, while exchanging heat with the outside world, to maintain the normal temperature of the body, mainly through heat convection, heat conduction, radiation, evaporation, etc. When the external environmental temperature is too high or the human labor intensity is very large, heat dissipation through sweat evaporation is the most effective way. Mine ventilation clothing is based on this concept. Therefore, mine ventilation clothing is produced with the aim of facilitating the entrance of external airflow into the micro-environment, so that the formation of forced convection promotes heat dissipation from the human body; on the other hand, airflow can also prevent sweat from adhering to the surface of human skin, promoting sweat evaporation and heat dissipation, so that the microclimate is improved and the temperature of human skin is reduced [21]. The heat transfer and cooling process system diagram is shown in Figure 1.

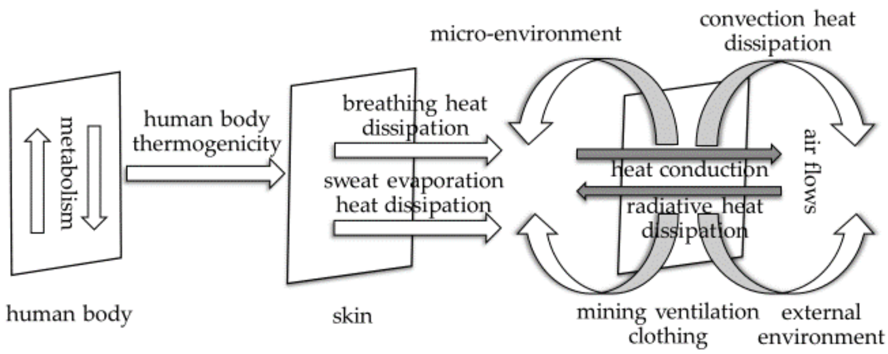


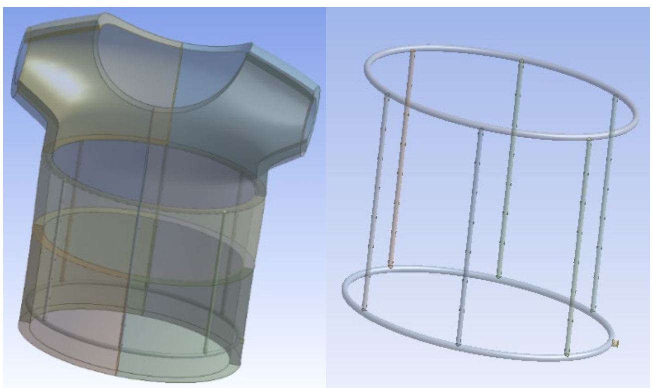
Figure 1. System diagram of heat transfer and cooling processes.

3. Three-Dimensional Physical Model Building and Parameter Setting

3.1. Physical Model Building and Simplification

In this study, SolidWorks software was used to establish a three-dimensional physical model of the torso of the human body wearing mine ventilation clothing. In the process of research, in order to simplify the model and reduce the complexity of the study, the thickness of mine ventilation clothing and the pipeline system were ignored in the simulation research process; the ventilation pipe system and mine ventilation clothing were not closely integrated, and there was a certain distance.

The process of establishing a three-dimensional physical model was as follows: We referred to the GB-10000-88 standard [22] to sketch the outline; then, we used the lofting function to allow it to take shape and used the functions of stretching and cutting, and other functions to process it in detail. In addition, the pipeline contour sketch was drawn; then, the model was built using functions such as stretching and combining, and the construction of the entire model was finally completed. The main feature attributes of the model were: thin-walled features were selected; the thickness of the garment microspace was set to 20 mm; the ventilation pipe system was arranged in the microspace; the interval between the vertical gas supply pipes was 150 mm; the interval between the upper and lower horizontal tubes was 350 mm; and the vertical ventilation pipe was arranged every 40 mm with a 3 mm outlet hole, for a total of eight small holes. The specific 3D physical model and pipe system are shown in Figure 2.



(**a**) (**b**)

Figure 2. Three-dimensional physical model and internal pipeline system diagram: (**a**) 3D physical model and (**b**) internal pipeline system.

3.2. Mesh Generation

The construction of the 3D physical model was the first step in the numerical simulation, and the second step was to divide the mesh. Based on the complexity of the three-dimensional physical model, the mesh was divided using the finite element method, and it was divided into non-structural meshes with good applicability; the meshes of the areas with large changes in speed gradient and mass capability transmission were encrypted, and the average growth rate was controlled below 1.2, which ensured that the mesh density was reasonable and reduced the time required for operation. In the model studied in this paper, the number of meshes was 3,914,505, and the meshing plot is shown in Figure 3.

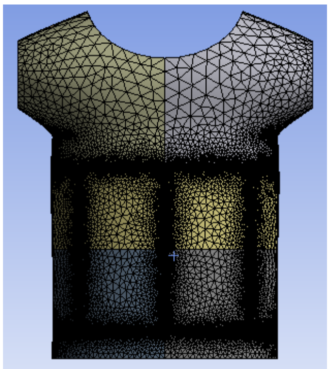


Figure 3. Grid diagram of mine ventilation clothing.

3.3. Boundary Condition

In the convective heat transfer system produced by human body–micro-environment–mine ventilation clothing, the inlet of compressed air was set as the velocity inlet, named velocity-inlet. The small holes in the gas supply branch pipe belonged to the inside of the system, so they could not be set as pressure outlets, which were internal boundary conditions, named interior. The compressed air outlets were the neckline, the cuffs, and the bottom of the garment and were set as pressure outlets, named pressure-outlet. Regarding the human skin layer, it involves convective heat transfer and radiation heat transfer, so it was set to mixed treatment, so that more accurate simulation data could be obtained [23,24].

3.4. Solution Methods and Parameter Settings

The solution method used is the "finite volume method". The turbulence model selected was the realizable k-ε model; the pressure and velocity coupling relationship was selected using the semi-implicit algorithm, that is, the SIMPLE algorithm; the pressure equation was set as PRESTO, and the second-order upwind was selected for discretization processing to obtain the discrete format of momentum, turbulence flow, turbulence dissipation rate, and energy [25,26].

We focused on the ambient temperatures of 28 °C, 30 °C, 32 °C, and 34 °C; the labor intensities of moderate labor intensity and heavy labor intensity (converted to 276 W/m^2 and 505 W/m^2); the ventilation volumes of 8 m^3/h, 11 m^3/h, and 14 m^3/h (converted to the inlet wind speeds of 34.93 m/s, 48.03 m/s, and 61.14 m/s); and the airflow temperature of 33 °C. The changes in the human skin temperature and micro-environment temperature of the staff who wore mine ventilation clothing made of different clothing materials were analyzed (the parameters of the clothing materials are shown in Table 1).

Table 1. Human skin and clothing material parameter value table.

	Density (kg/m^3)	Specific Heat J/(kg·K)	Thermal Conductivity W/(m·K)
Silica Gel	1400	1700	0.16
Pure Cotton	1550	1275	0.071
Modal Fiber	1520	1310	0.055

4. Simulation Results Analysis

4.1. Analysis of Human Skin Temperature Distribution

Through numerical simulation [27–29], the temperature distribution of the upper torso of the human body under different operating modes was obtained. Because the piping system design was the same, only one of the models could be taken for analysis, and the modal fiber type was selected here. As shown in Figures 4 and 5, for different ventilation volumes and different labor intensities, when the temperature variables were 28 °C, 30 °C, 32 °C, and 34 °C, the skin temperature changed of the human body wearing modal fiber type mine ventilation clothing.

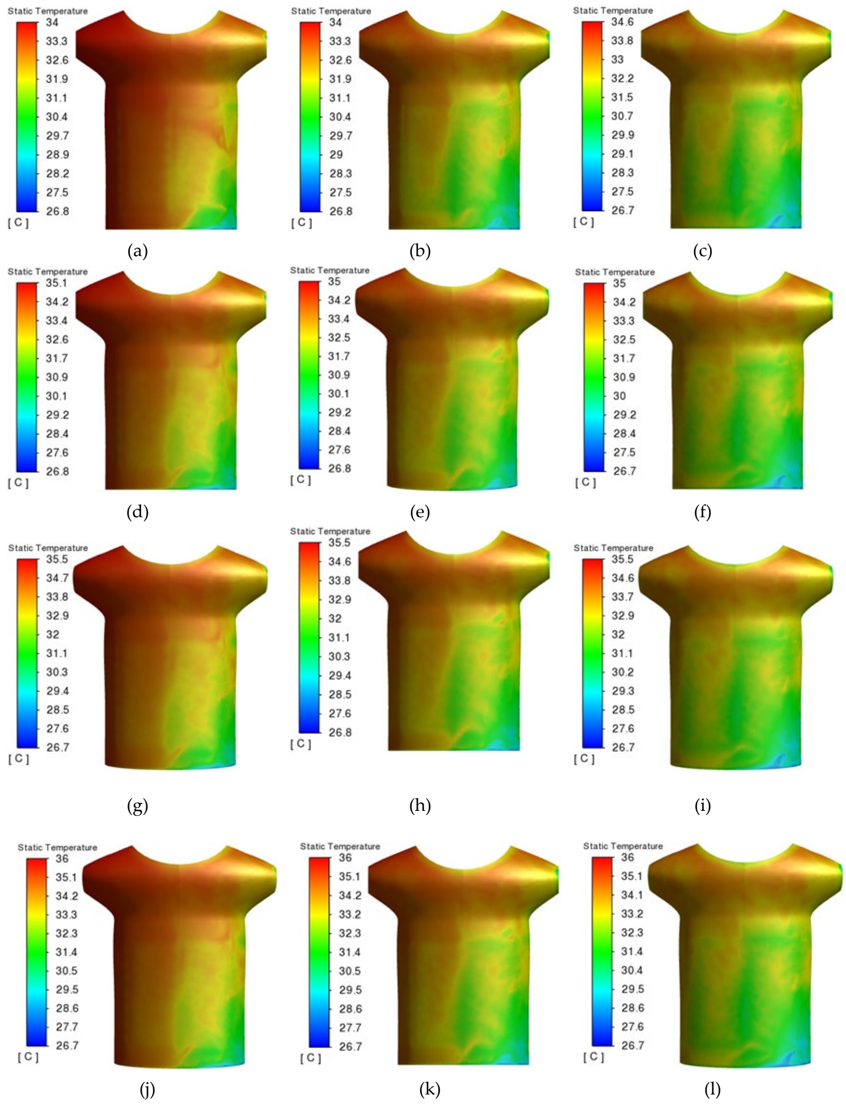


Figure 4. Human skin under moderate labor intensity. (**a**) Ambient temperature, 28 °C; ventilation volume, 8 m^3/h. (**b**) Ambient temperature, 28 °C; ventilation volume, 11 m^3/h. (**c**) Ambient temperature, 28 °C; ventilation volume, 14 m^3/h. (**d**) Ambient temperature, 30 °C; ventilation volume, 8 m^3/h. (**e**) Ambient temperature, 30 °C; ventilation volume, 11 m^3/h. (**f**) Ambient temperature, 30 °C; ventilation volume, 14 m^3/h. (**g**) Ambient temperature, 32 °C; ventilation volume, 8 m^3/h. (**h**) Ambient temperature, 32 °C; ventilation volume, 11 m^3/h. (**i**) Ambient temperature, 32 °C; ventilation volume, 14 m^3/h. (**j**) Ambient temperature, 34 °C; ventilation volume, 8 m^3/h. (**k**) Ambient temperature, 34 °C; ventilation volume, 11 m^3/h. (**l**) Ambient temperature, 34 °C; ventilation volume, 14 m^3/h.

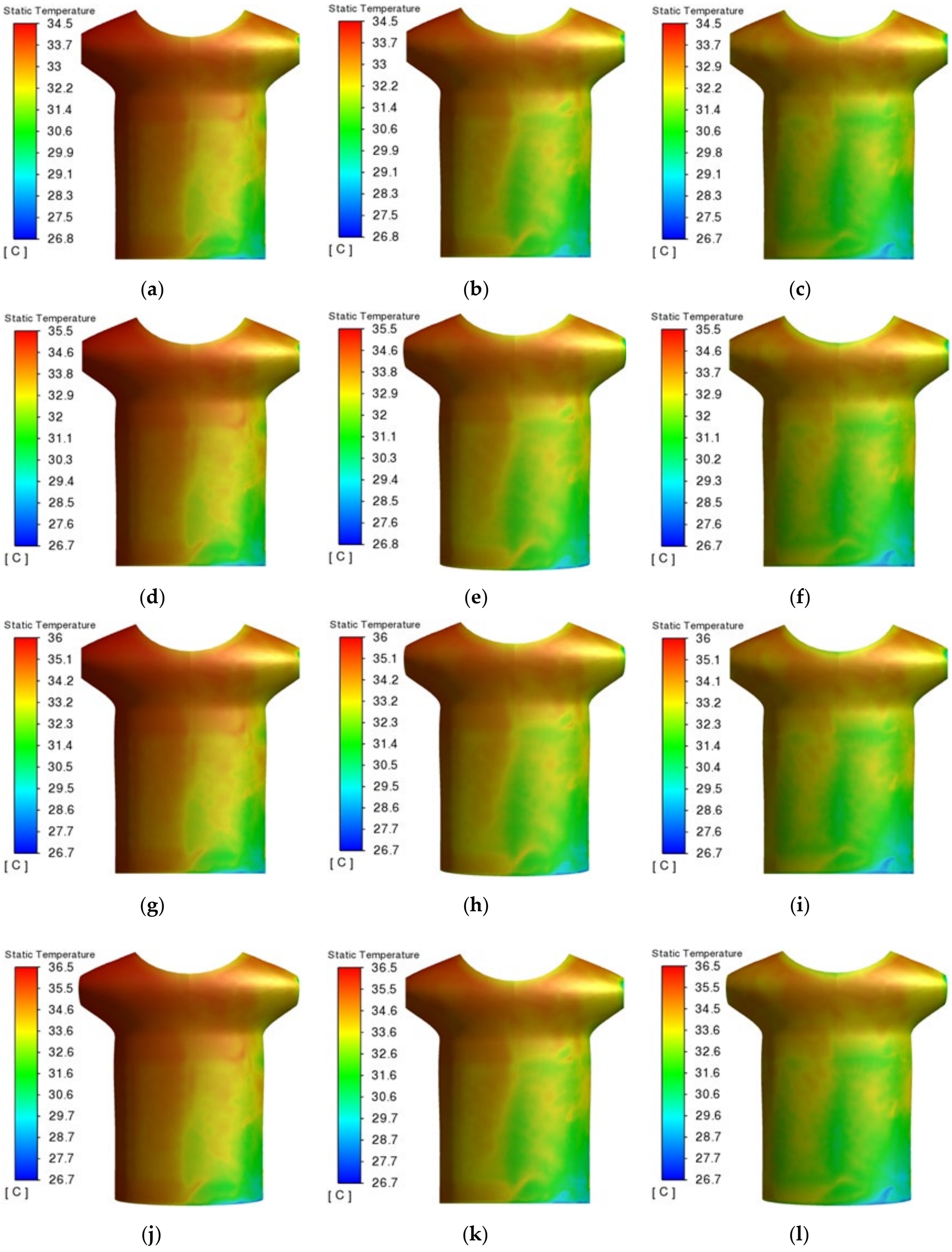


Figure 5. Human skin under heavy labor intensity. (**a**) Ambient temperature, 28 °C; ventilation volume, 8 m^3/h. (**b**) Ambient temperature, 28 °C; ventilation volume, 11 m^3/h. (**c**) Ambient temperature, 28 °C; ventilation volume, 14 m^3/h. (**d**) Ambient temperature, 30 °C; ventilation volume, 8 m^3/h. (**e**) Ambient temperature, 30 °C; ventilation volume, 11 m^3/h. (**f**) Ambient temperature, 30 °C; ventilation volume, 14 m^3/h. (**g**) Ambient temperature, 32 °C; ventilation volume, 8 m^3/h. (**h**) Ambient temperature, 33 °C; ventilation volume, 11 m^3/h. (**i**) Ambient temperature, 32 °C; ventilation volume, 14 m^3/h. (**j**) Ambient temperature, 34 °C; ventilation volume, 8 m^3/h. (**k**) Ambient temperature, 34 °C; ventilation volume, 11 m^3/h. (**l**) Ambient temperature, 34 °C; ventilation volume, 14 m^3/h.

From Figures 4 and 5, it was found that as the gradient of ventilation increased, the temperature of the skin decreased slightly, and the temperature of the skin was significantly reduced under minimum and maximum ventilation. This was due to the increase in the amount of ventilation; in the ideal case, the wind speed would also increase, and the convection and heat transfer speed inside the entire model would increase, so that the temperature of human skin would decrease. By comparing areas with ventilation pipe system arrangements with areas without ventilation pipes, such as the shoulder, it could be found that areas with ventilation pipes had much lower temperatures than areas without ventilation pipes, which showed that the internal pipeline system played a substantial role in cooling the human body. On the one hand, the shoulder was not covered by the pipeline; on the other hand, the gas flowing from the small holes first provoked a heat transfer with the micro-environment under clothing, and a heat exchange was carried out; then, it reached the shoulder, and the cooling effect became relatively poor. The temperature of the skin near the entrance area was lower than that of the areas away from the entrance, which was because the airflow flowed from the inlet to the far end through the pipeline system, and in this process, it exchanged heat with the micro-environment; then, it reached the far end, so the cooling effect away from the entrance was relatively poor, and the human skin temperature was relatively high.

4.2. Comparative Analysis of Human Skin Temperatures

In order to facilitate the analysis of human skin temperature data according to different models under different working conditions and to more intuitively compare the cooling effects of three kinds of mine ventilation clothing (modal fiber type, cotton type, and silica gel type), the simulation data were converted into line charts and column charts. The upper torso of the human body was divided into ten regions, namely, the left chest, right chest, left abdomen, right abdomen, middle, left shoulder, right shoulder, left waist, right waist, and central back, which were numbered in order with numbers 1 to 10. Figure 6 shows, for different ventilation volumes, different labor intensities, and temperature variables of 28 °C, 30 °C, 32 °C, and 34 °C, the comparison of the skin temperatures of the human body under the influence of three kinds of mine ventilation clothing. Figure 7 shows, for different ventilation volumes, different labor intensities, and temperature variables of 28 °C, 30 °C, 32 °C, and 34 °C, the comparison of the average skin temperatures of the human body under the influence of three kinds of mine ventilation clothing.

From the analysis of Figures 6 and 7, it could be seen thatwith the increase in labor intensity and environmental temperature, the temperature of the skin was significantly positively correlated with labor intensity and ambient temperature. It was negatively correlated with the amount of ventilation, which meant that it decreased with the continuous increase in ventilation, but the correlation was not as good as that with labor intensity and ambient temperature, and the skin temperature decreased with the increase in ventilation. This is mainly because the body metabolism increases with the increase in ambient temperature and labor intensity, and the body adjusts accordingly to increase heat dissipation to maintain the balance of the body temperature. The amount of ventilation does not directly affect the metabolism of the human body, and the body thermoregulation system can adjust the skin temperature accordingly, so that in the case of a change in ventilation, the temperature of human skin can also keep a dynamic balance in a certain range. The temperature of the skin was extremely related to the clothing material, that is, the cooling effect of mine ventilation clothing was quite related to the clothing material, which was because the breathability and moisture permeability of the clothing material had a great impact on the cooling effect of clothing. Clothing materials with good breathability and moisture permeability are conducive to the dissipation of human heat, can avoid the accumulation of sweat on the surface of the skin, and are conducive to evaporative heat dissipation and convective heat transfer.

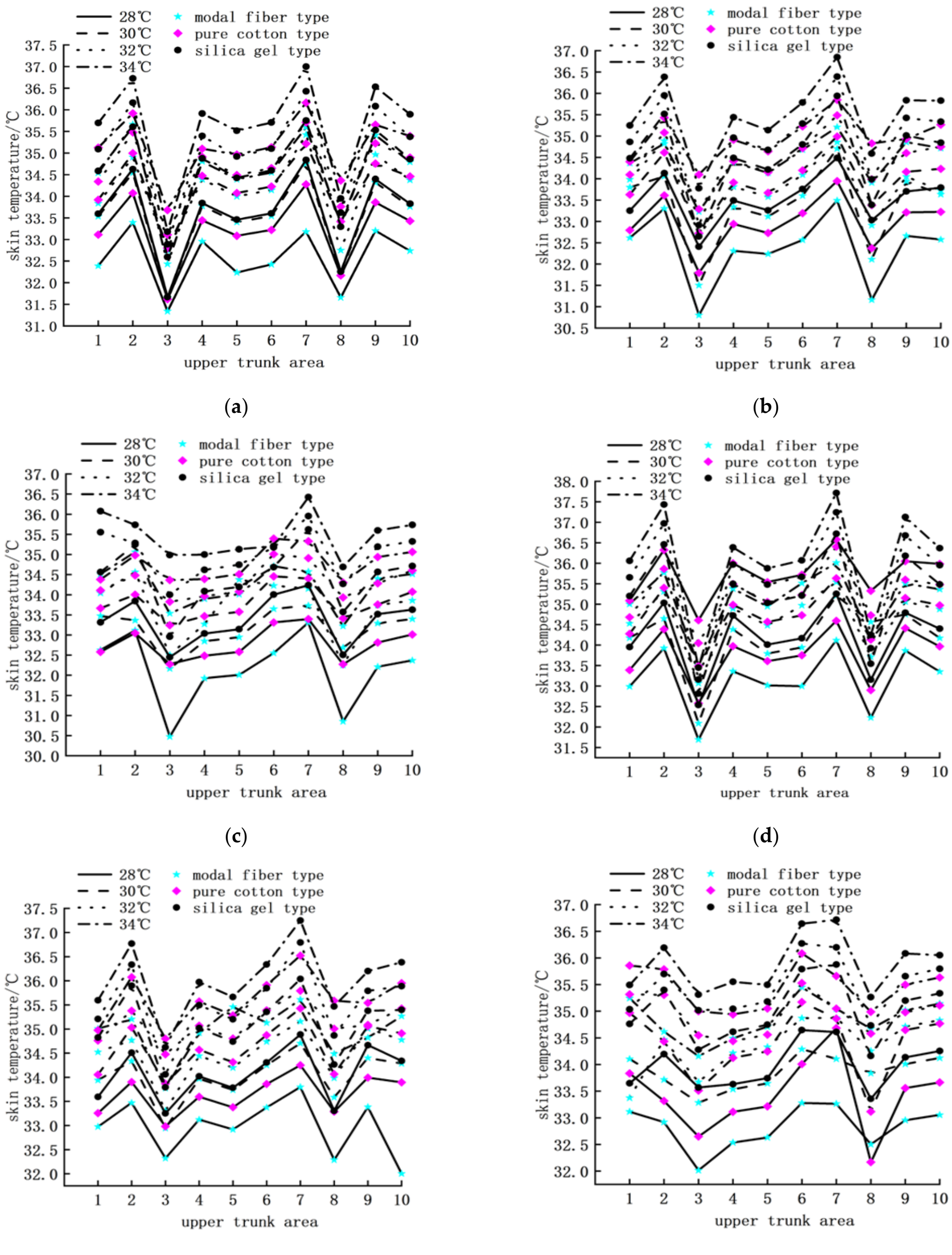


Figure 6. Comparison curve of human skin temperatures of various parts of the upper torso. (**a**) Moderate labor intensity; ventilation volume, 8 m^3/h. (**b**) Moderate labor intensity; ventilation volume, 11 m^3/h. (**c**) Moderate labor intensity; ventilation volume, 14 m^3/h. (**d**) Heavy labor intensity; ventilation volume, 8 m^3/h. (**e**) Heavy labor intensity; ventilation volume, 11 m^3/h. (**f**) Heavy labor intensity; ventilation volume, 14 m^3/h.

By comparing the average skin temperature according to different models, it could be seen that the cooling effect according to the three models was different under each operating mode. Among them, the human skin temperature obtained with the modal fiber type was 0.4 °C lower than that obtained with the pure cotton type, and the one obtained with the pure cotton type was 0.6 °C lower than that obtained with the silica gel type. The modal fiber type had the best cooling effect, followed by the pure cotton type and the silica gel type, in this order. In addition, it was observed under different operating modes, which also reflected the cooling effect of mine ventilation clothing and different environmental adaptations.

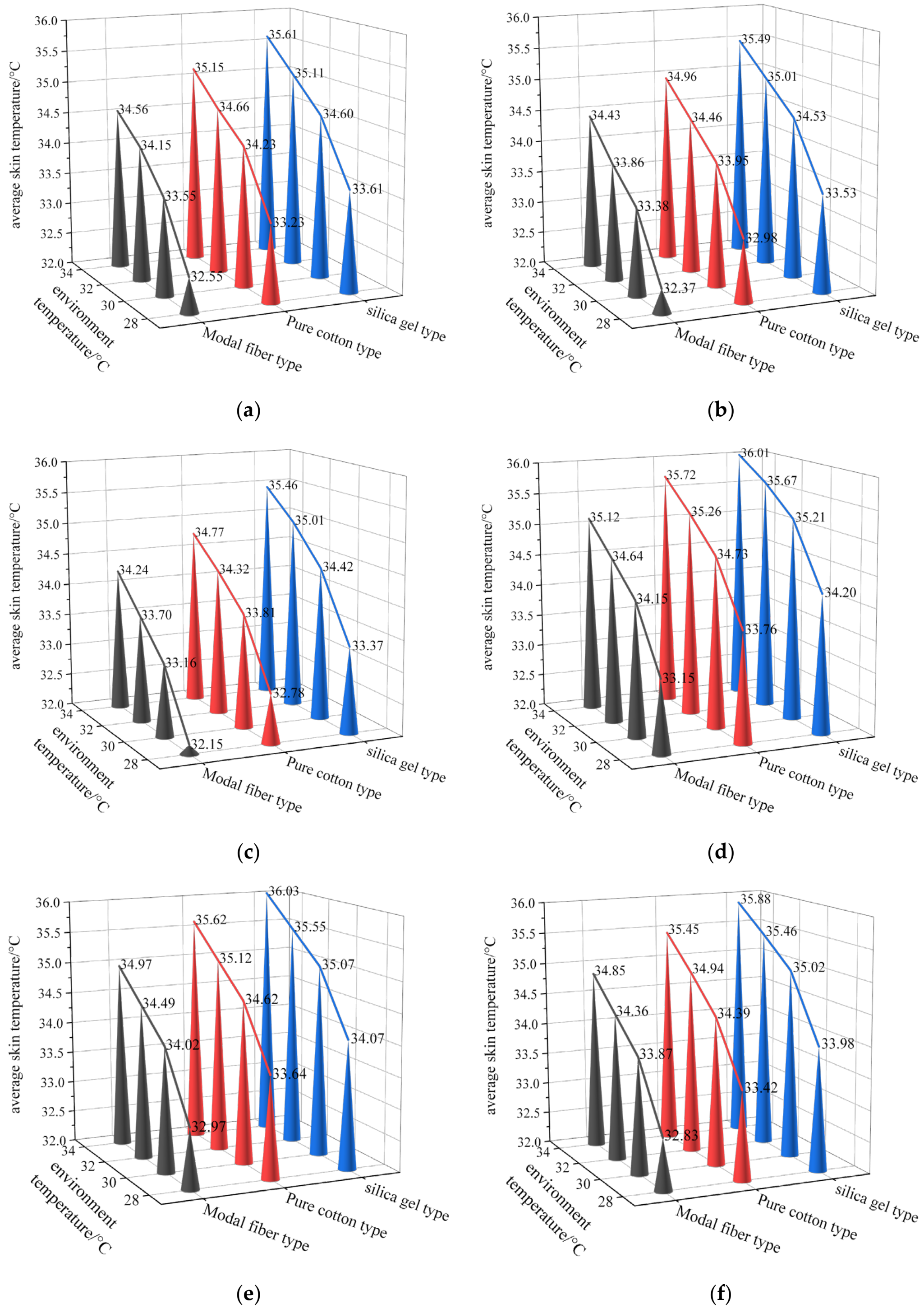
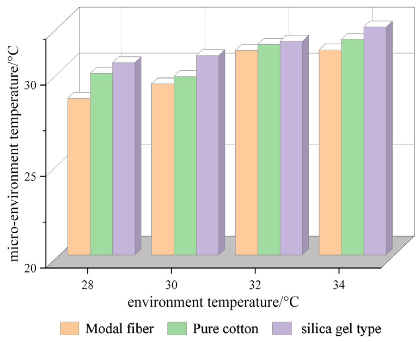
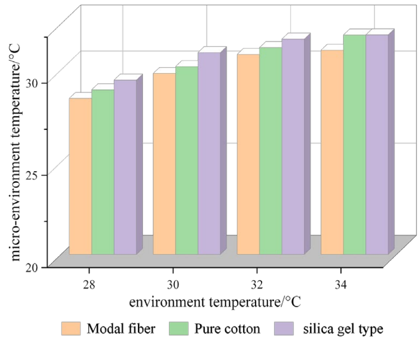


Figure 7. Comparison of the average skin temperatures in the three models. (**a**) Moderate labor intensity; ventilation volume, 8 m^3/h. (**b**) Moderate labor intensity; ventilation volume, 11 m^3/h. (**c**) Moderate labor intensity; ventilation volume, 14 m^3/h. (**d**) Heavy labor intensity; ventilation volume, 8 m^3/h. (**e**) Heavy labor intensity; ventilation volume, 11 m^3/h. (**f**) Heavy labor intensity; ventilation volume, 14 m^3/h.

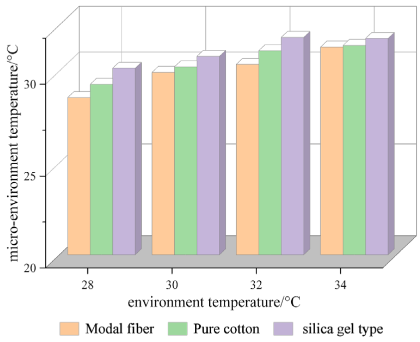
4.3. Comparative Analysis of Micro-Environment Temperatures

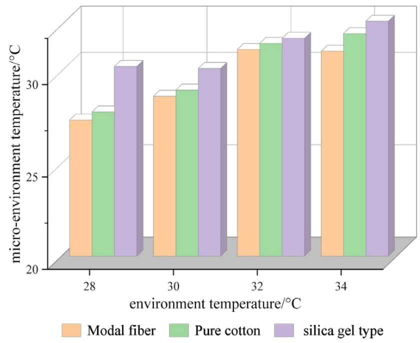
The micro-environment parameters were closely related to the cooling effects of mine ventilation clothing. The temperature of the micro-environment directly affected the change in the human skin temperature; we took the area-weighted average temperature data of each part of the micro-environment for comparison, under different operating modes, and the simulation results of the three models are shown in Figure 8. For different ventilation volumes, different labor intensities, and temperature variables of 28 °C, 30 °C, 32 °C, and 34 °C, the comparison of the micro-environment temperatures of the human body under the influence of three kinds of mine ventilation clothing is shown below.



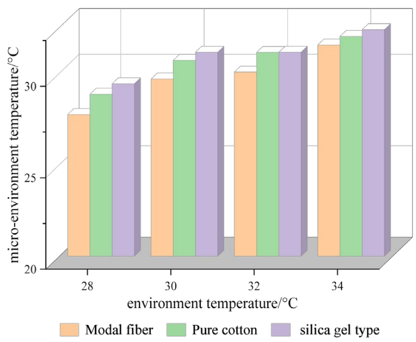


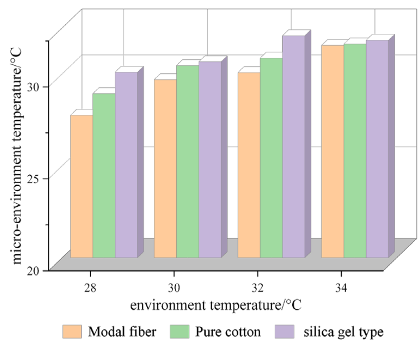
(**a**) (**b**)





(**c**) (**d**)





(**e**) (**f**)

Figure 8. Micro-environment average temperature comparison. (**a**) Moderate labor intensity; ventilation volume, 8 m^3/h. (**b**) Moderate labor intensity; ventilation volume, 11 m^3/h. (**c**) Moderate labor intensity; ventilation volume, 14 m^3/h. (**d**) Heavy labor intensity; ventilation volume, 8 m^3/h. (**e**) Heavy labor intensity; ventilation volume, 11 m^3/h. (**f**) Heavy labor intensity; ventilation volume, 14 m^3/h.

From the analysis of Figure 8, it can be seen thatwith the continuous increase in the ambient temperature, the temperature in the micro-environment also continued to rise. This is because the increase in the ambient temperature leads to an increase in the temperature of human skin, which leads to an increase in the heat dissipation from the human body; the heat transfer with the micro-environment is strengthened, so the micro-environment temperature continues to rise. By comparing the micro-environment temperatures obtained with different ventilation amounts, it could be found that the temperature change was not large, and the ventilation amount had little impact on the micro-environment temperature. By comparing the micro-environment temperatures in the three models, it could be seen that the modal fiber type resulted in a lower value than the pure cotton type and that the pure cotton type resulted in a lower value than the silica gel type; that is, the adjustment ability of the three models to the micro-environment was, from large to small: modal fiber type, pure cotton type, and silica gel type. Mine ventilation clothing had an impact on the micro-environment, and the breathability and moisture permeability of the garments had the promoting effect of improving the micro-environment.

5. Reliability of Simulation Results

In order to verify whether the human skin temperatures obtained via numerical simulation were consistent with the temperatures of the micro-environment under the garments, we conducted a comparative analysis of the human training test data obtained considering moderate labor intensity, the ventilation volume of 8 m^3/h, and modal fiber mine ventilation clothing. Under the same working conditions, Figure 9 shows the comparison of the skin temperature of 10 parts of the upper torso of the human body, and Figure 10 shows the micro-environment temperature comparison diagram.

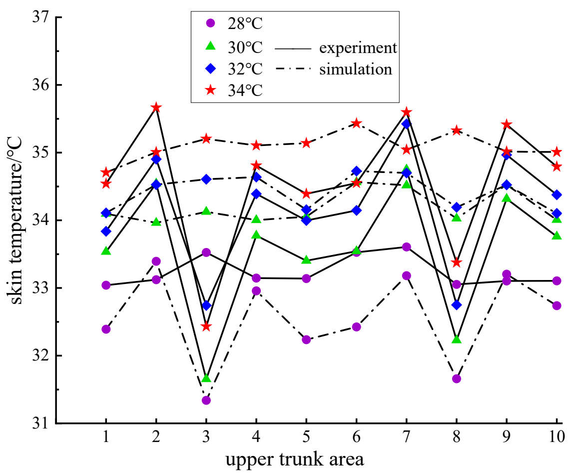


Figure 9. Comparison of skin temperature of 10 parts of the upper torso of the human body.

The difference and consistency between simulated and experimental skin temperature data can be visually compared in Figure 9. The average human body skin temperatures obtained via simulation were slightly lower than the average human body skin temperatures measured in the experiments. There were mainly two reasons: (1) The simulation was the result of calculation in the ideal state of mine ventilation clothing, while the test was affected by the actual situation. (2) Due to the influence of movement postures, the cooling effect of ventilation was limited, resulting in a more obvious difference between the cooling effect under the ideal conditions of the simulation and that in the test. Although there were large differences in specific locations, on the whole, the skin temperature data obtained from simulations and tests were distributed in the range of 32 °C to 36 °C. Under the same working conditions, the errors between the simulated data and the experimental data were within the acceptable range; that is, the average difference was within 0.8 °C.

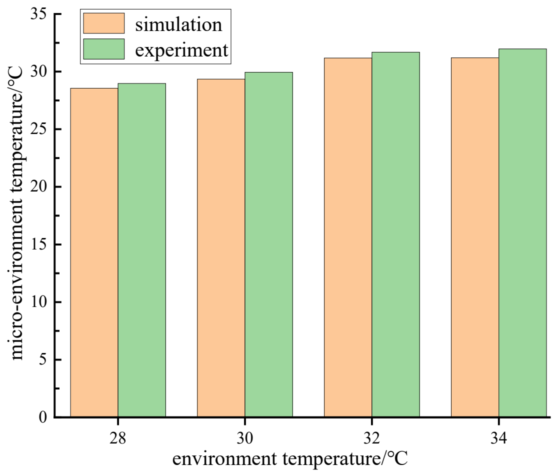


Figure 10. Micro-environment temperature comparison diagram.

According to the comparison between simulation and test data in Figure 10, the micro-environment temperatures obtained via simulation were slightly lower than those measured in the experiments, mainly for the following reasons: (1) The simulation was performed under ideal conditions, without considering the influence of surrounding environmental factors; on the other hand, in the experiments, because mine ventilation clothing cannot provide heat insulation, heat exchange occurred with the surrounding environment, resulting first in the change in the temperature of mine ventilation clothing and then in radiation into the micro-environment, making the temperature of the micro-environment increase. (2) There are air outlets such as cuffs and necklines in mine ventilation clothing, and these areas also exchange heat with the surrounding environment, leading to the increase in the micro-environment temperature. (3) Influenced by the movement state and labor intensity, the convection and heat transfer efficiency in the micro-environment was higher than in the ideal state simulation, resulting in higher micro-environment temperatures. Under the same working conditions, the errors between the mine ventilation clothing simulation data and the experimental data were within the acceptable range; that is, the average difference was within 0.6 °C.

The above results indicated that the errors between the numerical simulation data and the experimental data were within the acceptable range, regardless of the skin temperature or the micro-environment temperature. Therefore, the consistency between the simulation and the experimental data was good, and the conclusion was reliable.

6. Conclusions

(1) Through the analysis of the human skin temperature distribution map of the upper torso, it was found that the human skin temperature in the areas with ventilation pipe arrangement was much lower than that in the areas without ventilation pipe arrangement, and the human skin temperature near the entrance area was lower than that in the area away from the entrance;

(2) Through the analysis of the simulation results, the skin temperature of the human body obtained with the modal fiber type was 0.4 °C lower than that obtained with the pure cotton type, and the value obtained with the cotton type was 0.6 °C lower than that obtained with the silica gel type. The cooling effect of the three types of mine ventilation suits was modal fiber type > pure cotton type > silica gel type. The cooling effects of the three different clothing materials for mine ventilation clothing were stable, indicating they can adapt to different ambient temperatures and cool down the human skin;

(3) The micro-environment temperature obtained with the modal fiber type was lower than that obtained with the pure cotton type, and the value obtained with the pure cotton type was lower than that obtained with the silica gel type. Mine ventilation

clothing had an impact on the microclimate, and the breathability and moisture permeability of clothing had the promoting effect of improving the microclimate.

Author Contributions: B.Y., Methodology, Writing of manuscript, Formal analysis, Conceptualization, Project management, and Fund acquisition; J.Y., Verification, Visualization, and Translation and editing; J.L., Review and editing, and Software; H.L., Investigation; Y.L., Supervision; Q.H., Review; Y.Z., Review. All authors have read and agreed to the published version of the manuscript.

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References

1. Xie, C.; Nguyen, H.; Bui, X.N.; Nguyen, V.T.; Zhou, J. Predicting roof displacement of roadways in underground coal mines using adaptive neuro-fuzzy inference system optimized by various physic-based optimization algorithms. *J. Rock Mech. Geotech. Eng.* **2021**, *13*, 1452–1465. [CrossRef]
2. Zhang, X.; Zou, J. Research on collaborative control technology of coal spontaneous combustion and gas coupling disaster in goaf based on dynamic isolation. *Fuel* **2022**, *321*, 124123. [CrossRef]
3. Liu, H.Q. *The Study of Heat and Mass Transfer Theory and Cooling Technology in the Shaft and Tunnel that in the High-Temperature Mine*; Central South University: Chang Sha, China, 2010.
4. State Administration of Work Safety. *Safety Regulations in Coal Mine*; Coal Industry Press: Beijing, China, 2016; pp. 278–279.
5. QI, Y.D.; Cheng, W.M.; Yu, Y.B. Status summarization and progress of heat hazard control technology in coal mine of China. *Saf. Coal Mines* **2014**, *45*, 167–170. [CrossRef]
6. You, B.; Liu, J.F.; Shi, S.L.; Liu, H.; Lu, Y.; Zhang, M. Experimental study on influence of harsh environment of deep well on safety human factor indexes. *China Saf. Sci. J.* **2020**, *30*, 52–61. [CrossRef]
7. Qian, J.; Zhao, M.M.; Dang, T.H. Research progress on heat and moisture transfer model of clothing under forced ventilation. *Wool Text. J.* **2021**, *49*, 81–87. [CrossRef]
8. Udayraj, T.; Prabal, D.; Apurba, A.; Ramasamy, A. Numerical modeling of heat transfer and fluid motion in air gap between clothing and human body: Effect of air gap orientation and body movement. *Int. J. Heat. Mass. Tran.* **2017**, *108*, 271–291. [CrossRef]
9. Karim, N.; Afroj, S.; Lloyd, K.; Oaten, L.C.; Andreeva, D.V.; Carr, C.; Farmery, A.D.; Kim, I.-D.; Novoselov, K.S. Sustainable personal protective clothing for healthcare applications: A review. *ACS Nano.* **2020**, *10*, 12313–12340. [CrossRef]
10. Liu, H.Q.; Gao, L.Y.; You, B. Experimental study on factors affecting thermal comfortability of air cooling garment. *J. Xi'an Univ. Sci. Technol.* **2018**, *38*, 910–918. [CrossRef]
11. Guan, M.H.; Li, J. Garment size effect of thermal protective clothing on global and local evaporative cooling of walking manikin in a hot environment. *Int. J. Biometeorol.* **2020**, *64*, 485–499. [CrossRef]
12. Talukdar, P.; Das, A.; Alagirusamy, R. Heat and mass transfer through thermal protective clothing–A review. *Int. J. Therm. Sci.* **2016**, *106*, 32–56. [CrossRef]
13. Yang, Y.T.; Wang, C.; Tang, H.J.; Zheng, S.X.; Zhao, Y.X.; He, S.Y. Study on temperature field and velocity field of cooling T-shirt. *J. Qingdao Univ.* **2017**, *32*, 96–101. [CrossRef]
14. Chen, S.X.; Wu, W.D.; Sheng, W.; Wu, R.Y.; Pang, C.W. Study of airflow and heat transfer in air cooling garment under different types of air inlet distribution. *Cryog. Supercond.* **2010**, *38*, 43–47. [CrossRef]
15. Wang, Y.N.; Liu, G.; Huang, S.Y. Simulation Model of Microclimate under Clothing and Discuss about Factors Influencing Temperature and Humidity of Microclimate under Clothing. *Build. Energy Environ.* **2017**, *36*, 35–38.
16. Xu, P.F. *Research on the Flow and Heat Transfer in Air Cooling Garment Based on Thermoelectric Cooling*; Nanjing University of Aeronautics and Astronautics: Nan Jing, China, 2018.
17. Gao, R.X.; Tian, X.L. Simulation analysis of heat and moisture transfer laws in microclimate layers under different activity conditions of human body. *Shandong Text. Sci. Technol.* **2004**, *6*, 1–3.
18. Caroline, J.S.; George, H. Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. *Eur. J. Appl. Physiol.* **2011**, *111*, 1391–1404. [CrossRef]

19. Caroline, J.S.; George, H. Body mapping of sweating patterns in athletes: A sex comparison. *Med. Sci. Sport. Exerc.* **2012**, *44*, 2350–2361. [CrossRef]
20. Zhang, Y.; Dai, X.Q. The influence of fabric composition on the heat and moisture transmission performance of clothing. *Mod. Silk Sci. Technol.* **2021**, *36*, 32–36.
21. You, B.; Yang, J.; Zhang, Y.; Li, G.; Zeng, X.; Wang, S.; Luo, X. Research on the Distribution Regularity of Air Volume in the Pipelines of Mining Ventilation Clothing. *Geofluids* **2022**, 4117897. [CrossRef]
22. Hu, H.M.; Chao, C.Z.; Zhao, C.Y. Research on the correlation of Chinese adult human body size data. *Chin. J. Ergon.* **2014**, *20*, 49–53. [CrossRef]
23. Mao, C.; You, B.; Li, G. Research on the Influence of Ventilation Parameters of Mine Gas Cooling Suit on Human Skin Temperature. *Miner. Eng. Res.* **2021**, *36*, 67–73. [CrossRef]
24. Sun, Y.; Warren, J. Numerical modeling of heat and moisture transfer in a wearable convective cooling system for human comfort. *Build. Environ.* **2015**, *93*, 50–62. [CrossRef]
25. Mi, L.H. *Simulation of Flow and Heat Transfer between Air Cooling Garment and Surface Space*; Hunan University of Science and Technology: Xiangtan, China, 2019.
26. Shao, X.; Han, S.Q.; Gao, L.B. *ANSYS FLUNT 17.0 Flow Farm Analysis Example Tutorial*; Beijing University of Aeronautics and Astronautics Press: Beijing, China, 2018.
27. Mert, E.; Boehnisch, S.; Psikuta, A.; Bueno, M.A.; Rossi, R.M. Contribution of garment fit and style to thermal comfort at the lower body. *Int. J. Biometeorol.* **2016**, *60*, 1995–2004. [CrossRef]
28. Cao, J.; Xie, C.; Hou, Z. Ecological evaluation of heavy metal pollution in the soil of Pb-Zn mines. *Ecotoxicology* **2022**, *31*, 259–270. [CrossRef]
29. Xie, C.; Nguyen, H.; Choi, Y.; Armaghani, D.J. Optimized functional linked neural network for predicting diaphragm wall deflection induced by braced excavations in clays. *Geosci. Front.* **2022**, *13*, 101313. [CrossRef]