Analysis of Different Shape Ventilation Elements for Protective Clothing

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Abstract: People's thermoregulation may be hampered by exposure to extreme temperatures. Because of this, it is crucial to consider how fabric cooling and ventilation may affect human comfort while designing clothing. There is a demand on the market for more effective technical solutions and materials to be used in the external part of protective gear, while also ensuring the necessary ventilation even in warm environmental conditions and during heavy physical load. This is due to the growing interest in the market for efficient protection of the human body against exposure to extreme weather conditions. In this article a simple elliptical model of the body and the jacket is used to reduce the complexity of the problem. Five different shapes of ventilation elements named as E1 to E5 are designed for the study and the numerical results for the pressure, temperature and heat flux are calculated using SolidWorks Flow Simulation at three different inlet air velocity of 2, 5 and 8 m/s. The acquired results display interesting flow patterns and how the ventilation elements' shapes might influence the flow at various wind velocities. The results are compared and analyzed in terms of heat flux, pressure difference and temperature difference. The main objective is to determine which element's geometrical shape gives the smallest flow energy losses in the cell flow channel. If the pressure difference is higher, flow energy losses will also be high, and if the flow energy losses are higher, the body cooling decreases. The obtained results show that pressure difference increases gradually with the increasing inlet velocity. Moreover, results also indicates how different shapes of ventilation elements can affect the flow, pressure difference and flow energy losses. Based on analysis of obtained simulation results the most perspective ventilation element is proposed.

Key-Words: - flow simulation, protective jacket, ventilation element, heat transfer

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1 Introduction

Even in the temperate climate zone, the rise in average temperature brought on by climate change has raised the demand for additional outdoor cooling of the human body. The human body produces a substantial quantity of heat in hotter environments or under heavy physical load conditions, which must be expelled from the body to avoid dangerous overheating [1]. When human body temperature goes above specific point, sweating starts, this phenomenon occurs due the body's natural thermoregulation, as the heat emitted by the body is used by the evaporation of the liquid [2]. The circulation of air and the relative humidity at the body's surface determine the evaporation intensity. To improve perspiration in the airspace between the body and clothing, moist air or even saturated vapour must be evacuated from the body [3]. There are many venting methods for clothing [4], including various vents, the use of mesh fabric in various areas of clothing, and others, but they often do not fully ensure efficient air exchange and safety from various of external environmental conditions. For an instance, the mesh fabric offers effective body cooling and air circulation but is not resistant to radiations of sun, insect bites, or other mechanical effects, which can be crucial for various clothing items in hot environmental conditions. Commonly utilized breathable fabrics offer enough air permeability but usually inadequate body ventilation and mechanical shielding, for instance against several insect species like mosquitoes, which are transmitters of many hazardous diseases (e.g., dengue, malaria). Contrary, wearing garments made of thick textiles that offer sufficient protection against insects, greatly raises the danger of overheating of the body. There is necessity to use composite materials for protective apparel that will protect the body mechanically and enhance airflow between the body and the garment [5, 6]. The weight of the protective gear is not greatly increased while the essential ergonomic properties and aesthetic value are maintained by combining the essential characteristics of fabric (for example, elasticity, optimal weight to strength ratio) [7].

When dense fabric is used to ensure mechanical protection of the body against extreme weather conditions like sun radiations, dust, rain, insect access and their bites, the outer part of apparel may not have enough air permeability. As a result, warm, moist air may build up at the body, causing discomfort or even the possibility of overheating of the body. To enhance air exchange, multiple closable vents and open areas of garments have been developed [8]. However, this only results in a partial improvement in air exchange. The primary aspect of established approach is that it effectively protects the human body from the effects of extreme climatic conditions, ensuring the necessary air permeability under-clothing ventilation, and lowering the risk of overheating [9]. In order to meet the objective, different ventilation elements are designed, and a complex task of shape optimization of the element is carried out. There is a need for more effective technical solutions and materials to be used in the external part of protective suits, while also helping to ensure the required air circulation even in warm environmental conditions and during heavy physical load. This is due to the growing market interest in efficient human body protection against effects of extreme weather conditions.

2 Model for Ventilation Analysis

To reduce the complexity of the problem in this study, a simple elliptical shape model of the jacket and body are designed and assembled such that the body remains in center and jacket over it with a uniform gap of 2.2 mm in between. The schematic drawing of the model is shown in the figure 1. There is a single inlet ventilation hole of 2 mm diameter in front side and ten outlet holes of 4 mm diameter at the back side of the jacket.

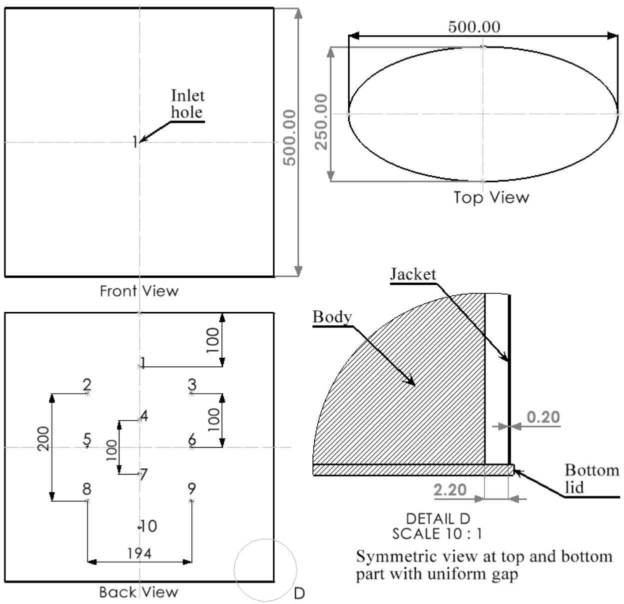


Fig. 1: Model design [10]

There are five different shaped ventilation elements are used in this study to analyze and compare the effectivity of each form. The shape and names of each ventilation elements are depicted in fig 2. The location of the ventilation element in relation to the jacket's inlet hole is indicated by a circle in the fig 2. The shape of element E4 and E5 is circular with different curvature, the main difference is that E4 has the position when element is attached tangent to the inlet hole, while E5 is attached concentric to the inlet hole.

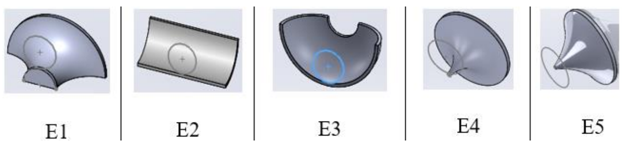


Fig. 2: Ventilation elements

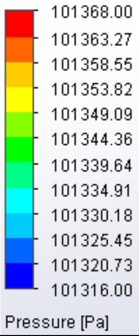
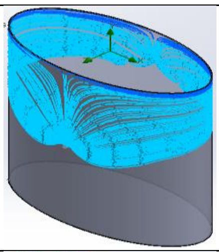
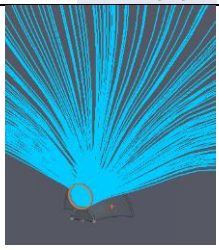
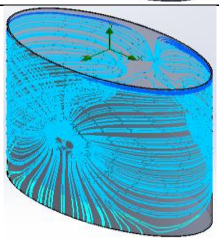
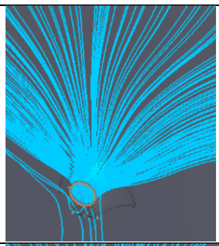
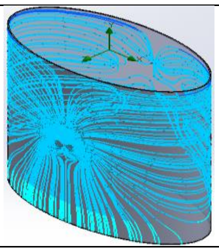
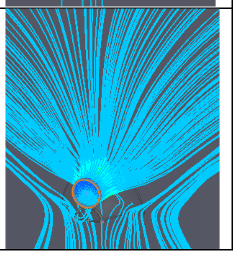
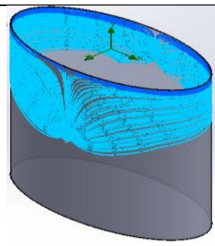
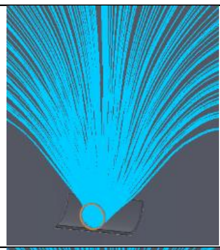
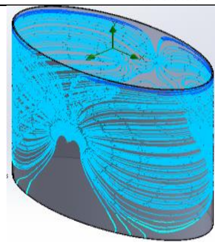
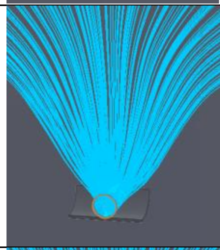
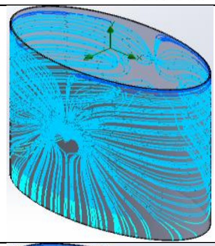
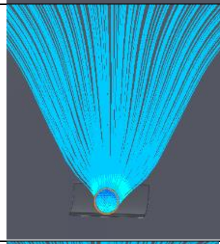
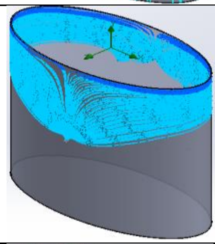
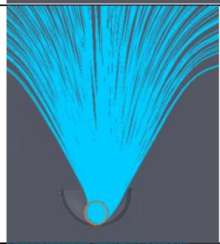
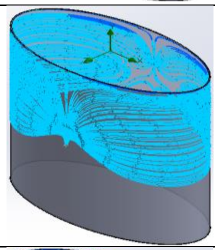
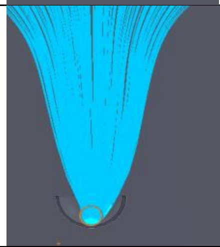
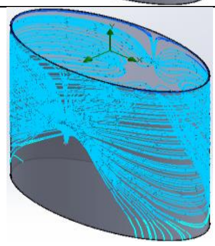
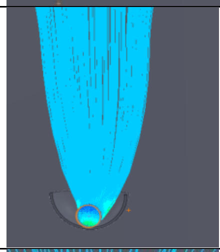
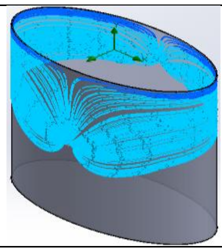
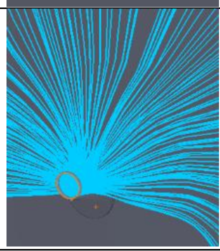
In this study results are obtained in SolidWorks internal flow simulation tool. The study is conducted at intake air speeds of 2, 5, and 8 m/s. In the initial boundary conditions, air temperature of 20 °C and environmental pressure of 101325 Pa, are set as standard values for the investigation. At the beginning of the simulation, distinct materials with particular material properties are assigned to the jacket and body. For all the ventilation elements, same material properties as of jacket is considered in the study. These materials properties are listed in table 1. The normal body temperature is set at 36.5 °C. It is also considered that human body generates 200 W of heat under normal walking condition [11].

Table 1. Material properties

Material property	Human body	Jacket
Average density [kg/m^3]	985	1420
Specific heat [J/kg. K]	3600 [12]	1140
Thermal conductivity [W/m. K]	0.21 [13]	0.261

3 Results and Discussion

The Flow Simulation study was performed with all the elements having the same set of values as discussed in the previous chapter, and the results are presented for the physical time of 5 seconds. Since this is a transient process, allowing longer physical time in the investigation will lead to longer computational time to obtain the solution. Moreover, difference in the obtained results would be almost same at any specific time; hence, to reduce computational time, smaller physical time of 5 seconds is selected for the study.

Element	Velocity [m/s]	Pressure Plots	
E1 	2		
	5		
	8		
E2 	2		
	5		
	8		
E3 	2		
	5		
	8		
	2		

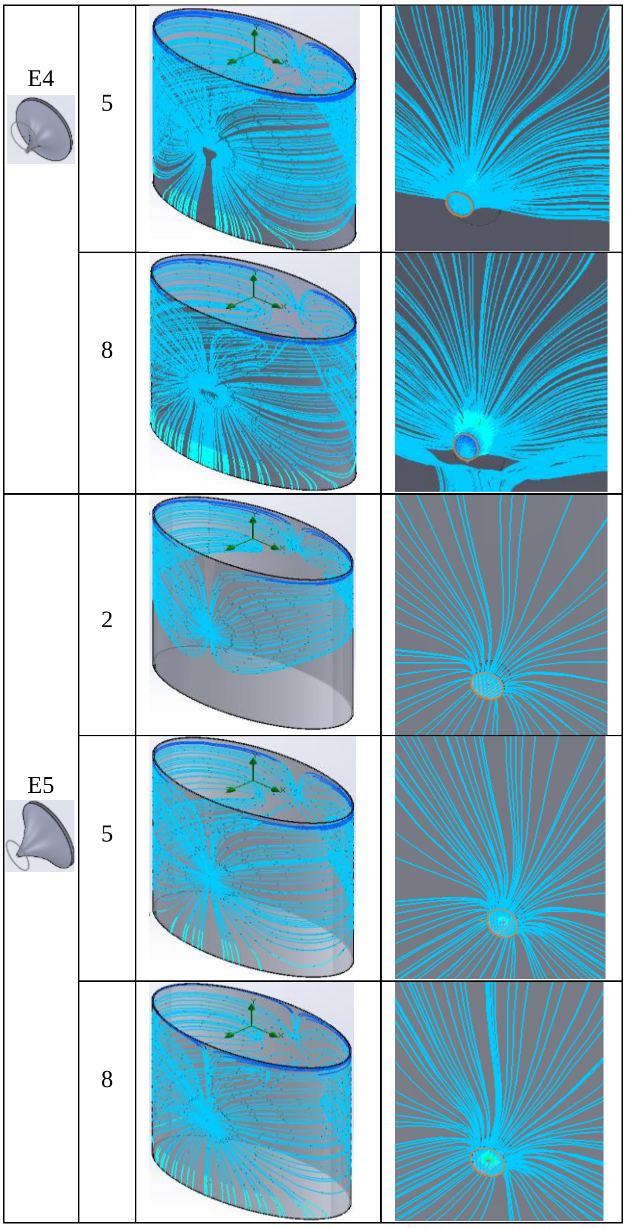


Fig. 3: Flow trajectories

Above fig 3, shows pressure distribution for each ventilation element at different inlet velocities. In order to compare the pressure distribution for all mentioned cases, an equal scale is used in each pressure plots, and the corresponding pressure values are listed in Table 2. The right column image in fig 3, is an enlarged view close to the ventilation hole to show how ventilation elements affect the flow route as well as pressure distribution at various air velocities. The left column picture is an isometric view of the pressure distribution over the entire model with the same color scale for easy comparison.

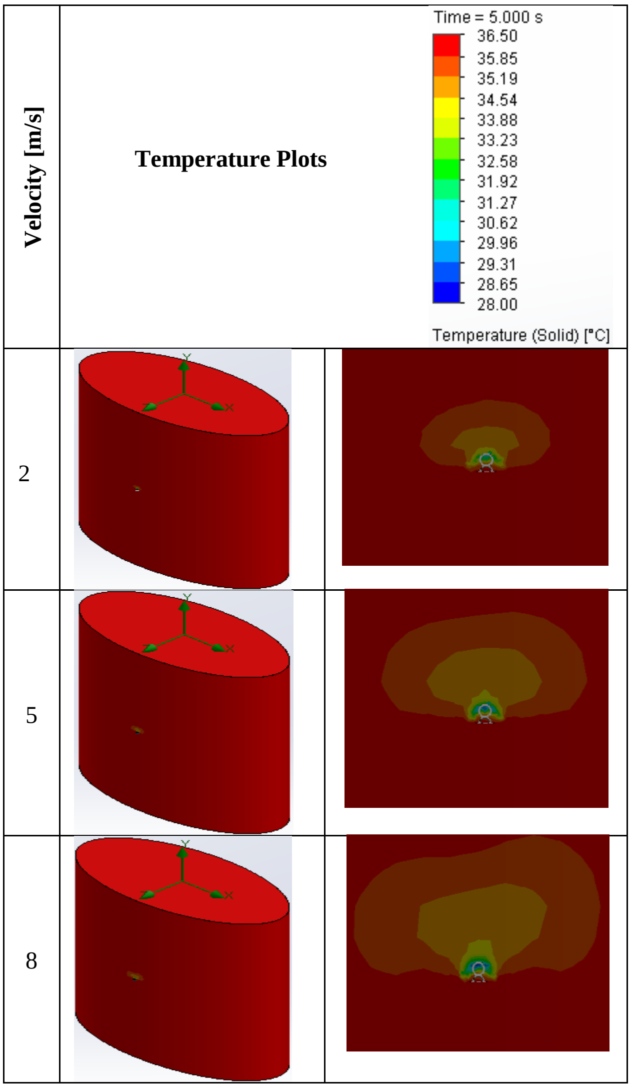


Fig. 4: Surface temperature for E1

The temperature plots for ventilation element E1 are presented in the fig 4, where left column shows temperature distribution over the entire solid body model, while right column is zoom view near the ventilation hole for easy visualization of temperature distribution near the ventilation hole. In a similar manner, temperature plots for other ventilation elements are examined, and obtained values of results are listed in Table 2. The temperature plots make it clear evident that when inflow velocity increases from 2 to 8 m/s, the cooling coverage area grows closer to the ventilation hole. This pattern is also true in case of other mentioned ventilation elements. To make comparisons and visualizations simple, an equal scale is used here.

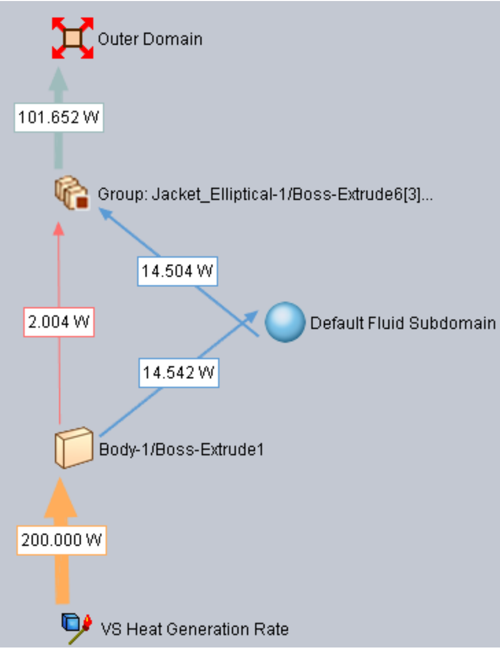


Fig. 5: Flux plot for element E1 at 2 m/s

In fig 5, Body-1/Boss-Extrude1 and Jacket_Elliptical-1 are references to the human body and jacket model respectively, while the Default Fluid Subdomain refers to the study fluid (air). The Outer Domain, in the flux plot depicts the amount of heat lost into the environment. As illustrated in figure 5, the flux plots are used to compute the rate of heat transfer in each case and obtained values for the respective elements are listed in the Table 2.

Table 2. Numerical values of results

Elements	Inlet Velocity [m/s]	Values	Pressure [Pa]	Temperature [◦C]
E1	2	Max	101329.45	36.50
		Min	101325.22	30.64
		Avg.	101328.06	36.50
	5	Max	101336.79	36.50
		Min	101325.25	29.30
		Avg.	101328.06	36.50
	8	Max	101349.03	36.50
		Min	101321.09	28.74
		Avg.	101328.09	36.50
E2	2	Max	101329.01	36.50
		Min	101325.22	32.78
		Avg.	101328.05	36.50
	5	Max	101333.80	36.50
		Min	101325.24	31.77
		Avg.	101328.04	36.50
	8	Max	101342.91	36.50
		Min	101323.10	31.17
		Avg.	101328.09	36.50
E3	2	Max	101329.28	36.50
		Min	101325.22	33.01
		Avg.	101328.05	36.50
	5	Max	101335.30	36.50
		Min	101325.16	31.86
		Avg.	101328.11	36.50
	8	Max	101344.94	36.50
		Min	101321.96	31.21
		Avg.	101328.12	36.50
E4	2	Max	101329.25	36.50
		Min	101325.19	32.69
		Avg.	101328.01	36.50
	5	Max	101335.55	36.50
		Min	101325.24	31.62
		Avg.	101328.03	36.50
	8	Max	101347.70	36.50
		Min	101322.24	31.22
		Avg.	101328.04	36.50
E5	2	Max	101329.28	36.50
		Min	101325.26	33.35
		Avg.	101328.04	36.50
	5	Max	101332.25	36.50
		Min	101325.27	32.89
		Avg.	101328.06	36.50
	8	Max	101338.54	36.50
		Min	101325.14	32.77
		Avg.	101328.08	36.50

Table 2 shows detail values of obtained results, Max, Min and Avg in the table refers to the maximum, minimum and average values of the results respectively. The given value of temperature shows surface temperature of the body. The pressure and temperature differences are calculated from the maximum and minimum values listed in table 2, while the heat flux is calculated from the flux plot as shown in fig 5. These obtained values of heat transfer, pressure and temperature differences are used for comparing effectivity of ventilation elements and proposing most effective ventilation element.

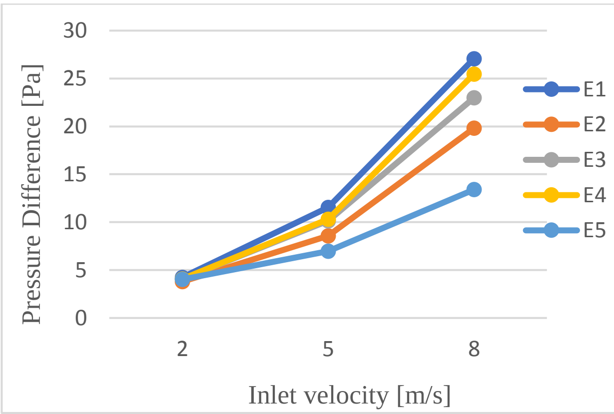


Fig. 6: Pressure difference v/s velocity

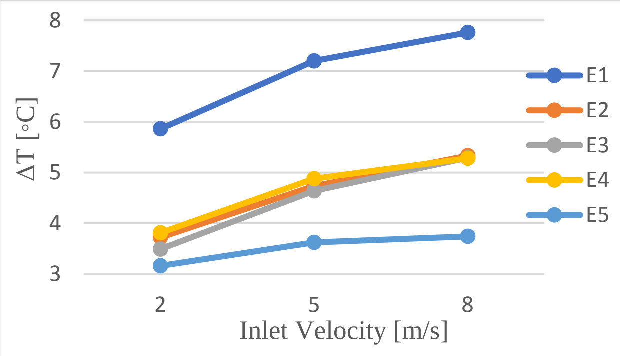


Fig. 7: Temperature difference (ΔT) v/s velocity

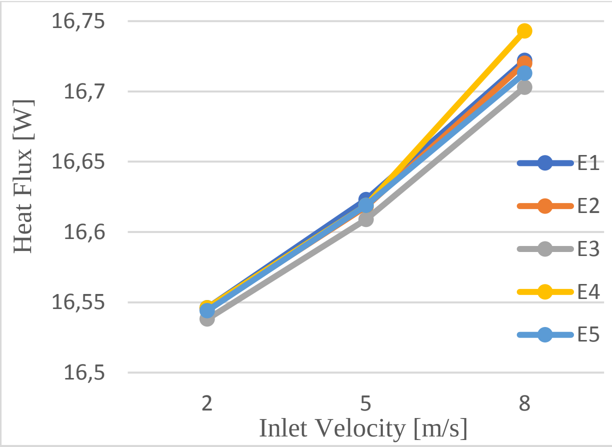


Fig. 8: Heat flux v/s velocity

Figure 6 indicates that all ventilation elements exhibit a steady rise in pressure difference from lower to higher air velocities. All elements initially exhibit nearly identical pressure differences at lower velocities of 2 m/s, but at 5 and 8 m/s, this gap steadily increases. Moreover, results with element E5 shows the lowest pressure difference of all the elements, which indicates better performance since the flow would be more uniform with less pressure variations. The element E5 produces a more gradual temperature variation with the increased velocity, which can be observed in fig 7, this results in less temperature swings due to air fluctuation and better comfort of the body. In the figure 8, mentioned values of heat flux is the total amount of heat transfer from body to jacket through the fluid for each element at different velocity. Since there is unit ventilation system in this investigation, heat transfer is nearly identical for all the cases. This is a crucial factor since a higher rate of heat transmission leads to increased body cooling.

4 Conclusion

The primary goal of this study was to determine which geometrical configuration of ventilation elements results in the lowest flow energy losses in the cell flow channel and may provide better cooling. From the obtained results and its comparison, it can be said that it is very important to consider the system's operating parameters to select the appropriate component, because some elements may work well at lower speeds but may not perform effectively at higher velocities. It is also evident from the results analysis that element E5 provides lowest pressure difference and smaller energy losses at the inlet flow channel than other mentioned elements in the study. A smaller pressure difference results in more uniform flow throughout the system and less flow fluctuations and when you have less fluctuations in the flow, energy losses are also small, which ultimately provide better cooling of the system. Moreover, E5 offers more gradual temperature difference at different inlet velocities, resulting in less variations of temperature due to air fluctuation. As a person moves in different directions, the air intake through the protective jacket's vents may come from various sides and angles, which may result in flow fluctuations. If there are higher temperature variations at different air velocities, it may cause higher temperature at one point and lower at other, which may create discomfort of the body.

Considering all the results and analysis points, element E5 is the most suitable of all the mentioned ventilation elements in the study, which could provide better cooling and comfort of the body. Predicting fluid flow and selecting effective element design is a complex task but it is possible through proper optimization and simulation analysis as mentioned in this study. In addition, the created models can be utilized for comparing ventilation effectiveness analysis, enabling further research, such as improving the positioning of various ventilation elements on protective garments.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Sanjay Vejanand carried out flow simulation and results analysis.
-Alexander Janushevskis gave contribution to problem statement and development of common 3D model as well as results interpretation.
-Agris Gulevskis gave contribution in development of detail shapes of ventilation elements and comparison of numerical results.

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