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# Finite element analysis of microclimate parameters in the metallurgical crane cabin

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*Introduction*. The article analyzes the microclimate parameters (temperature, speed and air pressure) in the metallurgical crane cabin provided by the air conditioning system using the finite element method integrated into the ANSYS software package. The metallurgical crane cabin air conditioning system was selected based on the engineering calculation of the required air flow rate supply, taking into account factors that affect the system performance, such as the location of the equipment and the degree of its dustiness.
*Problem Statement*. The purpose of this research was to check the efficiency of the air conditioning system of the metallurgical crane cabin, which was selected based on the results of the engineering calculations.
*Theoretical Part*. In the main part of the research, the distribution fields of temperature, speed and air pressure inside the cabin of a metallurgical crane were constructed, the values at the points of which were compared with the hygienic standards. In addition, the factors that affect the adequacy of the developed model were considered, namely the grid structure, the way to set the initial and boundary conditions.
*Conclusion*. The refinement of the analysis grid and the consideration of infiltration in the model eventually allowed us to get more correct results: the temperature at the characteristic points differ by no more than 1.3 °C, the speed values do not exceed the standard 0.3 m/s, the average normalized temperature of 24 °C is maintained in a volume of about 60-70 % of the total cabin volume.

***Keywords:*** metallurgical crane cabin, air conditioning, microclimate parameters, finite element analysis.

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**Introduction.** The working conditions of operators of technological and mobile machines are often characterized by high values of microclimate indicators, namely, temperature and intensity of thermal radiation. Affecting the employee, they can lead to a decrease in physical performance, the occurrence of colds and, after a year of work, occupational diseases of the cardiovascular and respiratory systems [1, 2].

To prevent cases of occupational diseases among employees of industries that are harmful in terms of microclimate parameters, such means of thermal protection of workplaces are necessary, the effectiveness of which is subject to the heightened requirements, for example, air conditioning systems.

**Problem Statement.** Many operating factors often remain unaccounted for in the calculation and selection of the air conditioning system of technological and mobile machines: dustiness of air and equipment, length and layout of the air conditioning system. In addition, it is also important to assess the extreme boundary weather conditions of the environment in which the machines can be operated. All this makes it possible to predict a possible decrease in the performance of the selected system during operation and to exclude a negative impact on the employee [3–5].

In this research, the task is to check the efficiency of the air conditioning system of the metallurgical crane cabin, for which its main characteristics were determined — the supply air consumption and cooling capacity. These characteristics include a correction factor that takes into account the pressure loss in the alignment lines, the way the internal and external unit of the system is located, as well as their contamination. The efficiency check is performed by constructing the temperature, speed, and air pressure fields inside the metallurgical crane cabin in the ANSYS software package.

The object of the study was the cabin of a metallurgical crane operated on the site of an arc steelmaking furnace (ASF) of an electric steelmaking shop.

**Theoretical part. Construction of the calculation area.** Based on the design three-dimensional model of the cabin in CAD, the design area was developed (Fig. 1). In the course of the work, the geometry of the cabin was slightly simplified; elements that slightly affect the general nature of the gas dynamics processes and obtaining the thermodynamic parameters of the model were excluded. Complex (small and saber-shaped) surface elements, edges, and gaps between surfaces were excluded from the geometry [6, 7].

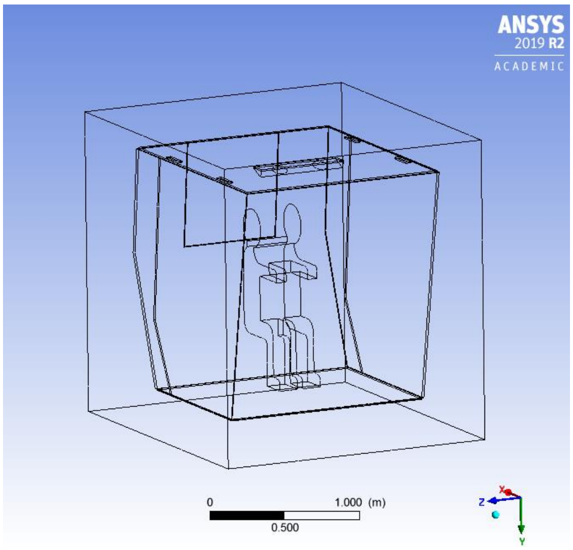
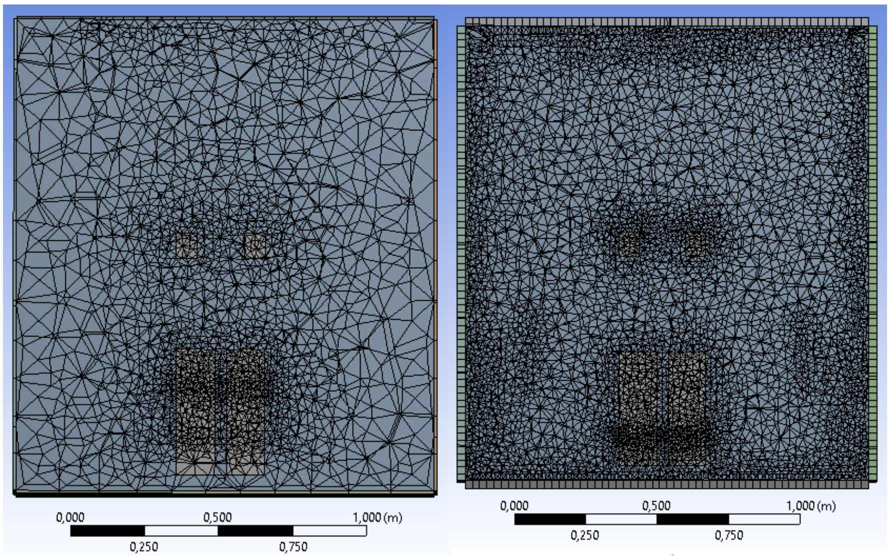



Fig. 1. Calculation area of the metallurgical crane cabin (front view)

The heat transfer through the multi-layer enclosure of the cabin, which affects the total heat flows, which were calculated using engineering techniques (from the heat balance of the cabin) and which were no more than 30 % of all heat flows, was taken into account by setting the thermal contact resistance in ANSYS. This coefficient integrates the values of the difference in temperature, thickness, and heat transfer coefficients between heterogeneous layers of fences, as well as heat flows.

**Calculation Grid.** The comparative calculation of the processes was carried out with a different grid structure: coarse — at the wall zone (the size of the elements — 0.15 m) (Fig. 2 a) and fine (the size of the elements — 0.025 m) (Fig. 2 b).




*a*) *b*)

Fig. 2. Calculation grid: a — coarse; b — fine

**Set initial and boundary conditions**. As other boundary conditions, the temperatures on the wall surface and the flow rates of the air supplied to the cabin, determined on the basis of engineering techniques, were used.

Table 1 shows the boundary conditions of the model. Heat input from sources of heat radiation on the ASF area were further set for some of the walls.

Table 1

Boundary conditions of the model

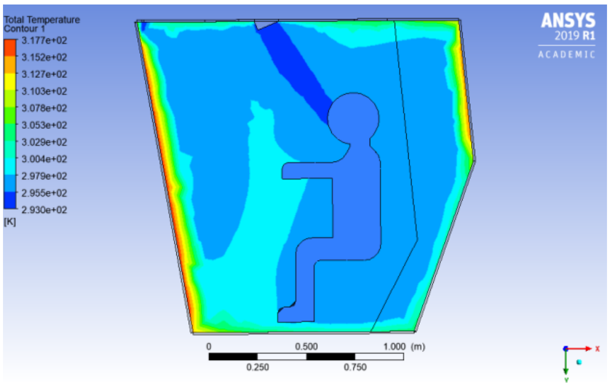
| No. | Wall type | Boundary conditions | | | |
|---|---|---|---|---|---|
| | | Ambient air temperature, °C | Heat input from the wall, W/m$^2$ | Heat input from heat radiation sources, W/m$^2$ | Thermal contact resistance, m$^2$·K/W |
| 1 | Front wall | 38.35 | 210 | 1445 | 0,11 |
| 2 | Side walls | | 104 | 951 | 0,09 |
| 3 | Upper wal | | 177 | – | 0,2 |
| 4 | Rear wall | | 59 | – | 0,19 |
| 5 | Floor | | 54 | 1705 | 0,32 |

**Results of modeling of heat and mass transfer in the cabin of a metallurgical crane (coarse grid of 0.15 m)**. The mathematical model of heat and mass transfer and the calculation of thermodynamic parameters and air flow mobility in the cabin of a metallurgical crane, performed in the ANSYS software package, on the one hand, allows us to clarify a detailed picture of the distribution of thermodynamic parameters in the cabin (temperature fields and air movement), and on the other — to consider the problem of determining pressure fields, the values of which have certain operational requirements. According to the performance requirements of the ventilation system, it should be sufficient to provide excess pressure in the combine cabin in the range of 50–200 Pa, taking into account air exchange with the external environment.

The calculation of air flow and thermodynamics in the unified cabin of grain and feed harvesters was modeled using the FluidFlow plug-in module (CFX). For this case, a more accurate model of turbulence was chosen — Shear Stress Transport (SST), which provides adequate behavior of the model equations in both the near-and far-field zones. This is due to the fact that the SST model uses the k-ω model to calculate the boundary layer, and the k-ε model to calculate the flow core at a distance from the walls. This, in fact, is the advantage of this turbulence model. The disadvantage can only be an overestimation of the level of turbulence in areas with high accelerations or in stagnant zones, which is not typical for this case [8, 9].

The SST model is described by equations similar to those of the standard k-ω model. The solution to the equations allowed us to obtain pictures of the distributions of the temperature, velocity, and pressure fields at the operator's workplace.

Figure 3 shows the calculated temperature distribution fields in the cabin relative to the deflectors and the operator (in different planes), Figure 4 shows the air velocity distribution fields in the cabin, and Figure 5 shows the pressure distribution fields in the cabin.

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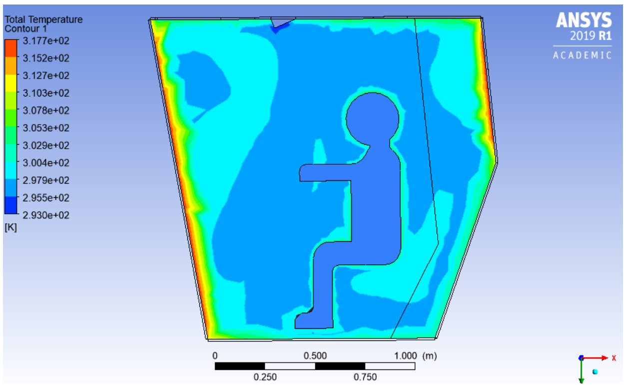


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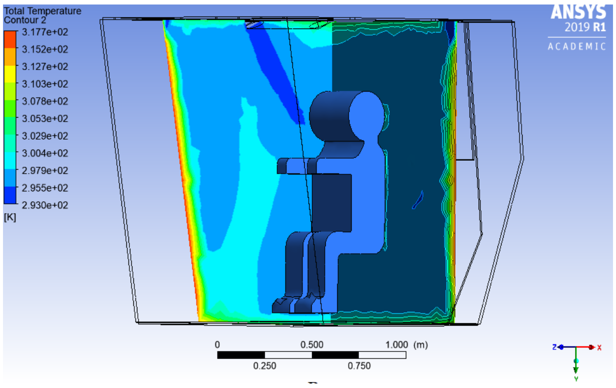


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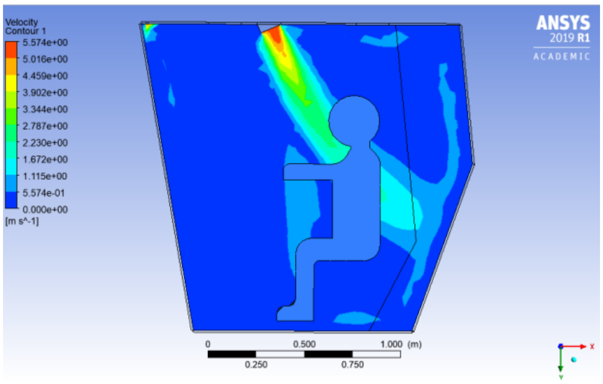
Fig. 3. Temperature distribution in the cabin of the metallurgical crane: a — relative to the deflectors (in the two-dimensional plane); b — relative to the operator (in the two-dimensional plane); c — relative to the deflectors (in the three-dimensional plane)

Based on the obtained results of constructing the temperature fields in the cabin (Fig. 3), the following conclusion can be drawn: the flow rate of air supplied to the cabin (680 $m^3$/h) with a given temperature (293 K or 20°C) determined by engineering methods will be sufficient to ensure the temperature in the cabin corresponding to the permissible class of working conditions 2 (297 K or 24 ° C). Therefore, the employee will not be adversely affected.

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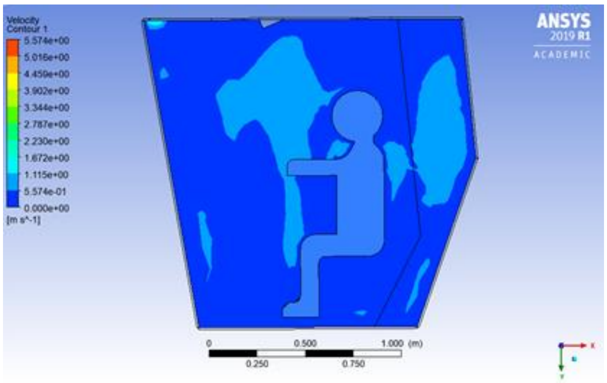


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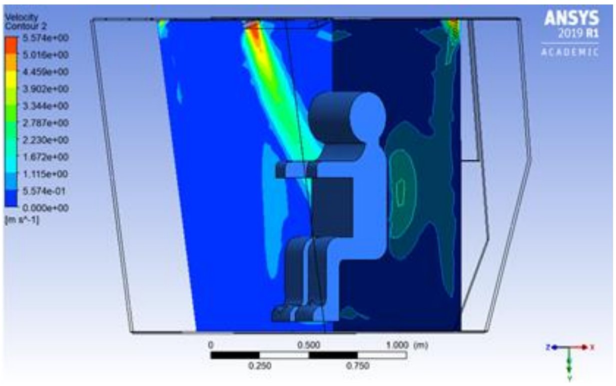


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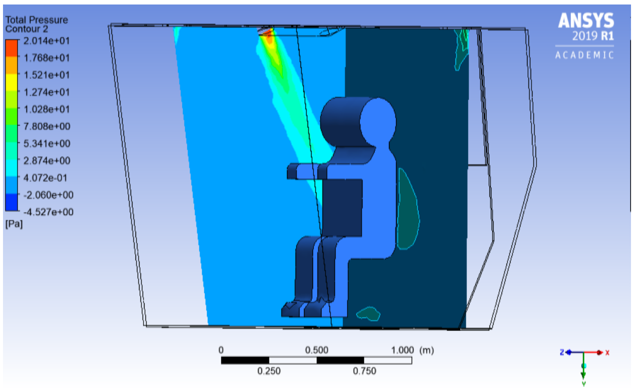
Fig. 4. Distribution of air velocities in the cabin: a — relative to the deflectors (in the two-dimensional plane); b — relative to the operator (in the two-dimensional plane); c — relative to the deflectors (in the three-dimensional plane)

Based on the results of building the fields of velocities in the cabin (Fig. 4), we can conclude the following: in certain engineering methods consumption supplied to the cabin air, the speed of air movement in the vicinity of the operator will be from 0.56 to 1.12 m/s, which exceeds the sanitary-hygienic standard set for acceptable working conditions (0.1–0.2 m/s). Therefore, the employee may have colds.

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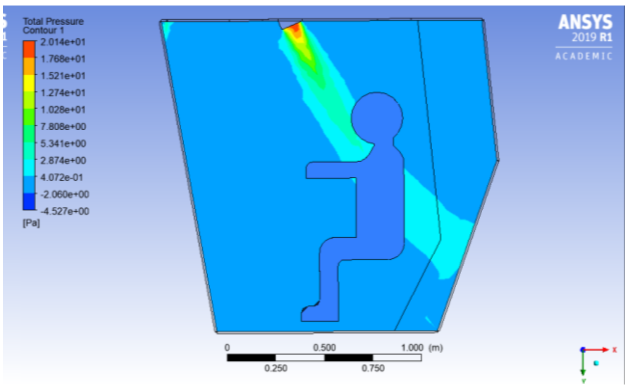


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Fig. 5. Pressure distribution in the cabin:a — relative to the deflectors (in the three-dimensional plane); b — relative to the deflectors (in the two-dimensional plane)

Based on the obtained results of constructing the pressure fields in the cabin (Fig. 5), the following conclusion can be drawn: the pressure in the flow of air supplied to the cabin at a flow rate determined by engineering methods is on average 2.87 Pa, which is presumably enough to achieve a pressure in the cabin greater than 50 Pa after the 15 minutes of the experiment. Unfortunately, with this approach, the ANSYS FluidFlow (CFX) tools do not construct a picture of a uniform distribution of pressure in a closed space when air is supplied inside. It is only possible to display the pressure in the supply air flow.

**Model verification (coarse grid of 0.15 m).** The ambient air temperature is measured at points 1–7 (Fig. 6) or at the points closest to them. It is recommended to measure the air velocity at a point at the operator's eye level (point 7 in Fig. 6) [10].

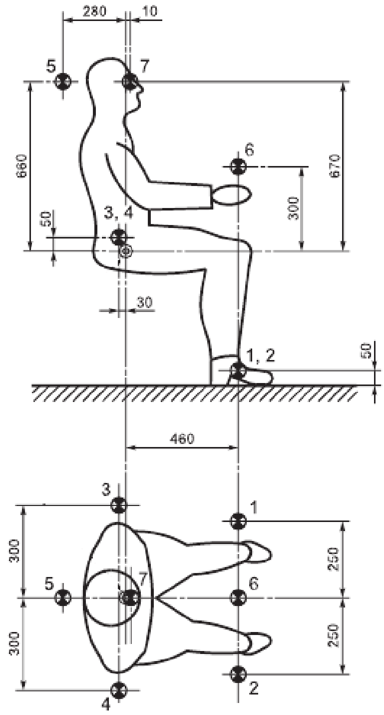


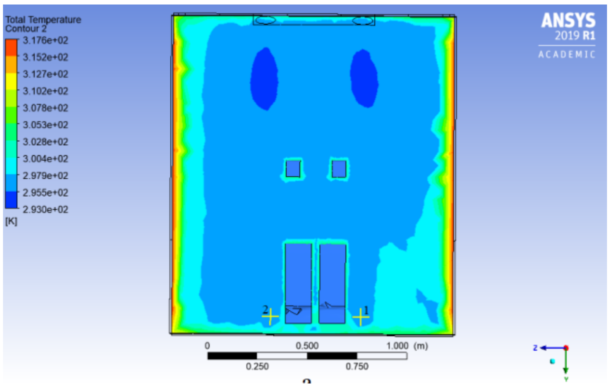

Fig. 6. Location of measurement points

General minimum operating characteristics:

– measurement results of the temperature of the operator's surrounding space should not differ by more than 5°C in all modes of air conditioning, heating or ventilation;

– it is recommended that the maximum air velocity in front of the operator's eyes (position 7 in Fig. 6) does not exceed 0.3 m/s.

Figures 7 and 8 show the calculations results of the values of temperature and air velocity.

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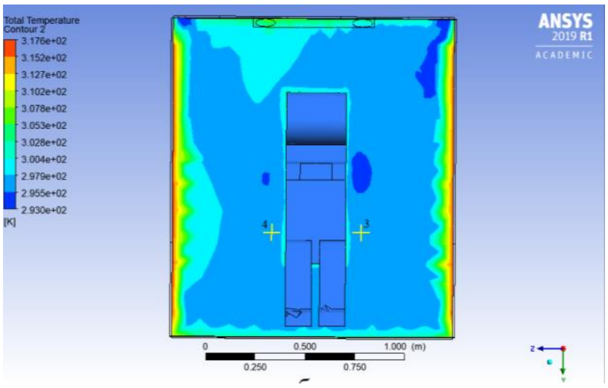


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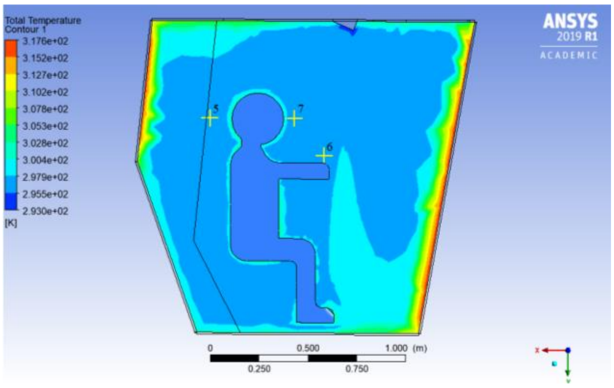


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Fig. 7. Results of temperature calculations:
a — at points 1, 2; b — at points 3, 4; c — at points 5, 6 and 7

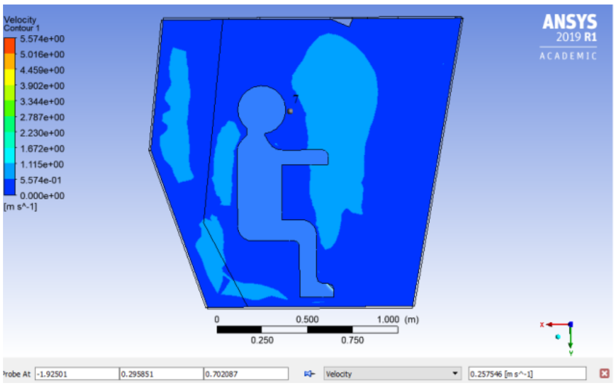



Fig. 8. The results of calculations of air velocity at point 7

As it can be seen from the measurement results, the temperature at all points is the same (297 K or 24°C), and the speed at point 7 does not exceed 0.3 m/s. Therefore, we can talk about the correctness of the calculated parameters of the air conditioner and the model as a whole in terms of achieving the required temperature and air velocity.

**Verification of the model (fine grid of 0.025 m).** The following changes were made to the fine-grid model:

1) The calculation was performed in the ANSYS 2019 R3 program.

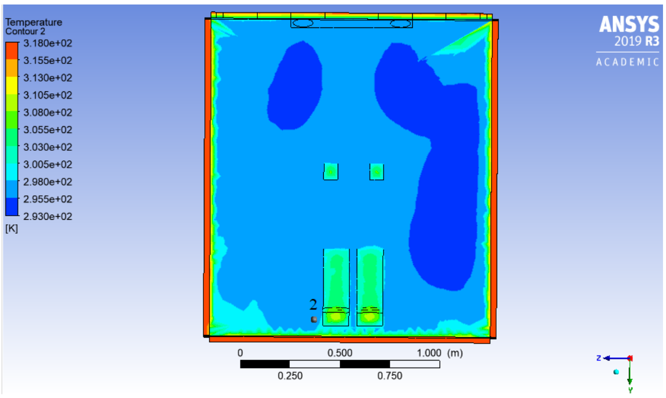
2) The size of the grid cells was changed from 0.13 m to 0.025 m, resulting in a total calculation time of 1 hour. In addition, the density of cells in the wall area is increased to refine the results of the heat transfer process through the wall.

3) The outflow of air from the cabin was set in a calculated way, taking into account the number of heat flows per infiltrated air. The flow rate of the infiltrated air calculated in this way was the boundary condition for the "Outlet" boundary.

4) The thermal resistance coefficient of the fence layers in the interfaces is taken into account.

The calculation results of temperature and velocity values are shown in Fig. 9–10.

As it can be seen from the results of the calculations, the average temperature in the cabin in the overwhelming volume of its space is up to 70 % the same (297 K or 24°C), which indicates a weak influence (0.2–0.5°C) of a smaller grid on the final results of the calculation as a whole. The speed at point 7 does not exceed the standard 0.3 m/s.

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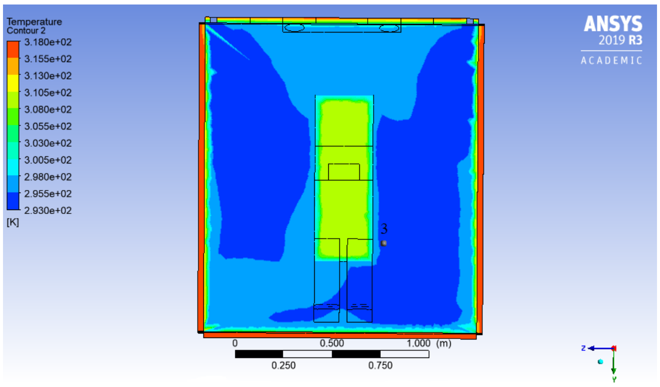


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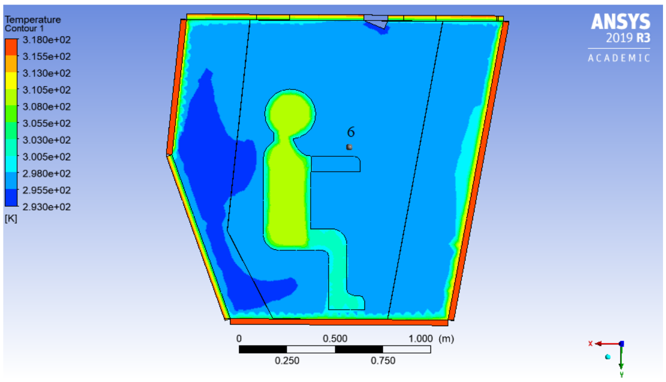


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Fig. 9. Results of temperature calculations: a — at point 2; b — at point 3; c — at point 6

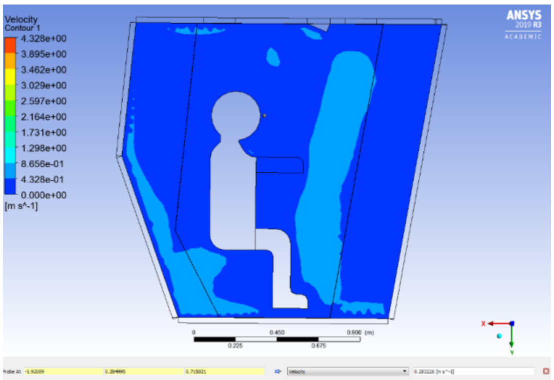



Fig. 10. Results of speed calculations at point 7

**Comparison of the results of model calculations with experimental data**. The results of the experiment are taken from the special assessment of working conditions of the driver (Taganrog Iron & Steel Factory (TAGMET)):

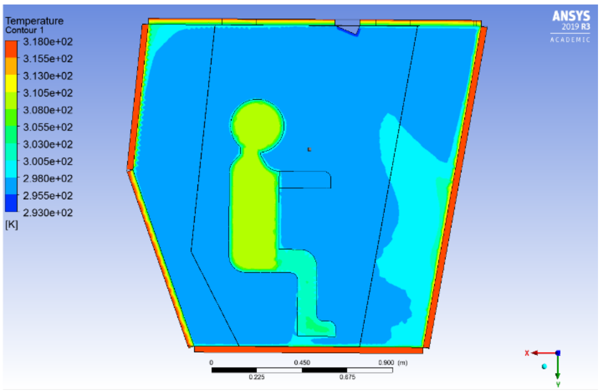
1) The ambient temperature during testing — 39.4°C.

2) The maximum difference between the average air temperature in the cabin and the ambient temperature is 15.7°C.

3) Humidity in the cabin — 27 % (outside 15 %).

4) The established average temperature in the cabin — 24.6°C.

The results of the model calculations are shown in Fig. 11.

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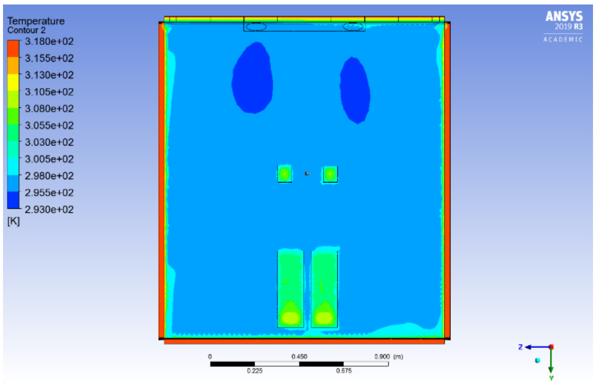


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Fig. 11. Average cabin temperature: a — side view; b — front view

Based on the results of the model calculations, it can be concluded that the discrepancy between the experimental and model values is no more than 0.16°C. This fact gives the right to speak about the adequacy of the created model in terms of achieving the required temperature and air velocity.

**Conclusion.** The refinement of the calculated grid and taking into account the infiltration in the model, ultimately, allowed us to get more correct results: the temperatures at the characteristic points differ by no more than 1.3°C, the speed values do not exceed the standard 0.3 m/s, the average normalized temperature of 24°C is maintained in a volume that is about 60-70% of the total volume of the cabin. As for ensuring the necessary air pressure in the cabin of the metallurgical crane, with this approach, the ANSYS FluidFlow (CFX) tools do not assume the construction of a picture of a uniform distribution of pressure in a closed space when air is supplied from inside. It is only possible to display the pressure in the supply air flow. The solution to this problem is possible with a more careful adjustment of the boundary conditions of the model.

In general, the finite element analysis allows us to solve a rather important problem from the point of view of industrial safety — preventing a decrease in the performance of the air conditioning system by rational selection of the equipment at the design and forecasting stage, as well as achieving microclimate parameters due to this.

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*Contribution of the authors:*

V. V. Maslensky — calculations, text preparation, analysis of the results of the study, formulation of the conclusions; Yu. I. Bulygin — formulation of the main concept, goals and objectives of the study, finalization of the text, conclusions correction.