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METHODOLOGY OF ANALYTICAL RESEARCH OF THE MICROCLIMATE OF THE BUS DRIVER'S CAB USING THE ANSYS-FLUENT SOFTWARE ENVIRONMENT

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Summary. *The article analyzes the current state of microclimate problems in vehicle cabins, studied in the world and in Ukraine. An analysis of the scientific research of some scientists working in this field is carried out, as well as the state of regulatory documentation, both abroad and in Ukraine. With the help of mathematical dependencies, a description of the theory of air mass transfer is provided. Calculations of air flows in the front part of the bus cabin, in particular in the driver's working area, were carried out using the ANSYS-Fluent software environment.*
Key words: *heating system, microclimate, driver's workplace, air flow, air circulation, FEA, air temperature, air velocity, thermal state. ANSYS-Fluent.*

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Statement of the problem. The trend towards urbanization, accompanied by the growth of the population in cities, requires an increase in the number of urban transports. Passengers who use public transport (buses, trolleybuses, trams, metro or city railway) must ensure comfortable transportation. The components of transportation comfort include such concepts as: passenger capacity, smoothness, environmental safety and thermal comfort in the cabin and at the driver's workplace. Thermal comfort is essential, because the vehicle's driver is responsible for traffic safety. Incorrect microclimate indicators can negatively affect the well-being of the driver. Namely, they can increase his irritation or reduce his reaction during an extreme situation. As a result, there is an increased risk of road accidents [1].

A favorable microclimate also carries an economic aspect. Passengers will prefer those vehicles where the microclimate in the cabin is more favorable, so transport companies that have vehicles with a comfortable microclimate will have an economic advantage over others.

There is no worldwide regulatory documentation on the microclimate of salons [2] because the climate in different countries is different (for example, the climate in Norway is significantly different from the climate in Israel or Europe). There are some countries with several climate zones (for example, Argentina, USA, China, etc.). Therefore, it should be considered when researching or developing one or another kind of vehicle. Regulatory documentation on the microclimate currently does not exist in Ukraine [2], so manufacturers are forced to use the basis of the requirements from other countries with a similar climate. Governments usually form their own methodologies for determining microclimate parameters and also tell us which specific parameters need to be determined:

- air temperature;
- air velocity;
- air humidity;
- the noise level coming from the devices of the microclimate system;

- the level of harmful substances in the air, etc.

Microclimate parameters in the vehicle’s interior according to GOST R 50993-96 are shown in Table 1 [3, 4].

Table 1

Standardization of the microclimate in the vehicle interior according to GOST R 50993-96

Season of the year	*Vehicle type*	*Air temperature, °C*	*Relative humidity, %*	*air velocity, m/s*
Cold and transitory periods of the year	Passenger cars	20–23	60–40	0,2
	Trucks and buses	18–20	60–40	0,2
Warm period of the year	Passenger cars	20–25	60–40	0,2
	Trucks and buses	21–23	60–40	0,3

Investigating the temperature balance in city bus cabins is not an easy task. Such vehicles make frequent stops during their route, often open their doors and drive at relatively low speeds. Therefore, we have a temperature imbalance in certain areas of the bus cabin due to the environment's influx of cold or hot air. It is difficult to determine the amount of heat at different interior point, both practically and theoretically, when the bus interior is filled with passengers. The reason is that when passengers are placed unevenly, the air heating in different parts of the cabin is uneven, so there are so-called discomfort zones where passengers can feel overheated. It should also be taken into account that the temperature in the cabin is controlled by the driver personally on most domestic buses. After all, the presence of automation that would regulate the temperature at different points is not cheap and requires additional maintenance, so every manufacturer can not afford it.

Analysis of the available investigations. Experimental studies [5–7] were carried out on a regular city bus route in Zhytomyr (Ukraine) using air-conditioned buses. The value of internal and external temperature, relative humidity was measured. The results were compared with the calculated values and comfort requirements for the summer season according to ASHRAE. Experiments have confirmed that at an external air temperature of +24˚C in the bus cabin, under appropriate conditions of transportation, the desired regulatory microclimate is not provided and the cabin ventilation system needs air conditioning.

The temperature and ventilation mode study of a large city bus cabin is shown in [8]. A solid-state bus model has been developed. Simplified calculation area was derived on the basis of the preliminary analysis, in which the incomplete flow of air around the bus is realized. The Navier-Stokes equations are averaged over Reynolds to calculate turbulent spatial flows. The calculations were made at three different speeds and at several configurations of the ventilation channels: the windows are closed; only the ventilation hatches on the roof are open. An assessment of the microclimatic conditions in the bus cabin was carried out for compliance with the requirements of regulatory documents.

Intercity buses can be parked in the sun for a long time before the trip. The internal temperature of the bus can reach 60°C in such a case. An experimental study was conducted to determine the correctness of installing the air conditioning system on a bus prototype in work [9]. Indoor and outdoor temperatures, evaporator inlet and outlet temperatures, and relative humidity values were measured. Thermal comfort values were calculated according to ASHRAE standards. Thermodynamic analysis of the bus air conditioning system was carried out in studies [10–16]. The valuable and reversible work of the compressor, the coefficient of performance and the energy efficiency of the cabin air conditioning system were obtained and evaluated in detail.

The study [17] aims to demonstrate the possibility of THESEUS-FE (software) for calculations and modeling of the microclimate system operation. At the first step, the results of calculations using the THESEUS-FE finite element method were confirmed, comparing them with those obtained using the internal research results at MAN. In the second step, the advantage of using THESEUS-FE was demonstrated by creating an advanced simulation model that would also simulate passengers' thermal comfort.

The bus interior heating system is one of the most energy-intensive, in terms of electricity consumption. As a rule, large city buses are equipped with at least four interior heaters, which are attached under the passenger seats to their frames. This leads to problems with the bus's electricity balance, especially in winter operating conditions, when starting the engine is difficult and the electricity consumption of the passenger compartment lighting system increases. In addition to energy consumption, a significant problem in passenger transport is internal noise, one of the sources of which is the operation of heater fans. In order to determine the noise characteristics of the heaters, comparative tests [18] were conducted on a large city bus. Noise levels were measured in the octave range of frequency bands f on the A scale of the noise meter in dBA.

The microclimate study of an electric bus (taking into account its features) using computer analysis is shown in [19]. The method is based on the CFD analysis of the interior of an electric bus in a steady state without taking passengers into account. Against the background of limited energy resources in traction batteries, the use and interconnection of highly efficient individual components and intelligent heat management are the main conditions for achieving acceptable operating ranges [20].

Air conditioning and heating of the passenger cabin in an electric bus leads to a significant increase in energy consumption. It’s due to the limited capacity of the battery, the daily operating range of electric buses depends significantly on the surrounding climate. Therefore, the choice of heating and air conditioning has a significant impact on the operating costs of an electric bus. The purpose of this study [21] is to conduct a cost analysis for different heating systems of the interior of an electric bus. Research [22] is carried out at the VTT technical research center in Finland. A team of researchers has developed methods for studying HVAC system consumption in cold season conditions (for cities in Finland) on electric city buses with batteries.

There is a trend of urban rail transport development (city electric trains and rail buses) in large European cities for today: S-Bahn (Germany, Switzerland, Austria), RER (Paris), FR (Italy), HEV (Budapest), etc. Therefore, it is important to provide comfortable conditions for passengers in this type of city transport. Studies [23–24] show what designs of HVAC systems exist today and investigate how air conditioning and heating inside a salon can be improved.

The Objective of the work were:

1) to investigate how air circulation created by heating devices in the bus driver's cabin affects the microclimate of the bus cabin;
2) analyze the method of heat calculation at the bus driver's workplace;
3) model the circulation of air masses in the ANSYS-Fluent software environment;
4) draw conclusions according to the research results.

Statement of the task. The main task of this work is to investigate air circulation at the bus driver's workplace using the ANSYS-Fluent software unit and draw conclusions based on the obtained results.

Analysis of the mass transfer theory. The basic equation in the dynamics of liquids and gases is the Reynolds averaged Navier–Stokes equation. The velocity in this case is divided into two components [25–28]:

$$u_i = U_i + u_i^{'} \tag{1}$$

where U_i – the main component of velocity;
$u_i^{'}$ – the velocity component due to vibrations.

The instantaneous Reynolds averaging of the Navier–Stokes equation can be written as follows:

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{2}$$

$$\rho \frac{\partial U_i}{\partial t} + \rho U_j \frac{\partial U_i}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} - \overline{u_i u_j}\right)\right] \tag{3}$$

$$\rho \frac{\partial T}{\partial t} + \rho U_j \frac{\partial T}{\partial x_j} = -\frac{\partial}{c_p \partial x_j}\left(k \frac{\partial T}{\partial x_j}\right) - \frac{\partial \overline{u_i T}}{\partial x_j} \tag{4}$$

where ρ – flux density;
μ – dynamic viscosity of the substance;
u – flow velocity;
P – pressure in a liquid or gas;
T – liquid or gas temperature;
t – flow time;
x_i – position tensor in coordinates x, y, z;
c_p – specific heat capacity of a substance;
k – thermal conductivity;
u_i u_j – Reynolds stress tensor.

The temperature difference in the flow area will cause a change in density and, as a consequence, flow forces must be taken into account. Streams caused by fluidity move due to changes in density in the fluid region. Density variations are negligible based on the Boussinesq approximation. Basically, it is assumed that the flow is incompressible, that is, the density is constant in all terms except for the body's gravity. This assumption is a fundamental approximation of Boussinesq.

Then the gravity term is written in the form of equation (5), as a function of the gravity acceleration, the temperature difference and a property of the material called the coefficient of thermal expansion, β:

$$F = (\rho - \rho_0)g \approx -\rho_0 \beta (T - T_0) g \tag{5}$$

Substituting equation (4) into the momentum equation, we get:

$$\frac{Du}{Dt} = -\frac{1}{\rho}\nabla p - g\beta(T - T_0) + v\nabla^2 u \tag{6}$$

It should be noted that the laminar form is used for clarity in the equations (6).

Modeling air flows in ANSYS-Fluent. ANSYS is a powerful commercial PC with a graphical interface and covers a wide range of hydrodynamics and thermodynamics problems., An engineer needs to have experience using the finite element method to carry out calculations. The package runs on Windows OS.

The following problems can be simulated in the ANSYS PC in the field of hydrodynamics and thermodynamics:

1) compressible and incompressible flows;
2) flows with a moving boundary;
3) flows with a free boundary;
4) interaction with solid bodies, submerged bodies;
5) porous media;
6) turbulence;
7) cavitation;
8) acoustics;
9) heat exchange;
10) turbines, rotating machines;
11) multiphase flows, boiling;
12) currents that chemically react with each other and combustion.

We need to set the following initial calculation conditions for simulation in the ANSYS-Fluent software environment, which are listed in Table 2.

Table 2

Boundary conditions for modeling in ANSYS-Fluent

	Parameter	*Unit*	*Meaning*
1	Air blowing velocity	m/s	0.5
2	Air temperature	K	300
3	Convection for static air	$W/(m^2\ K)$	25

Our calculation will be based on modeling the movement of thermal masses in the frontal part of the bus cabin based on a simplified spatial solid model (Fig. 1) of the interior space. FEA mesh is generated by the Ansys-Fluent environment with its further visualization of the air masses movement of air masses in the bus cabin (Fig. 2–4).

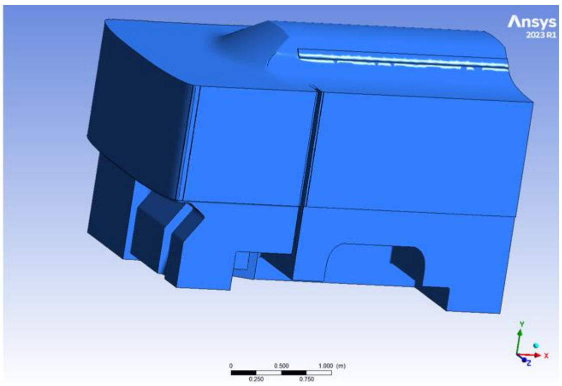

Figure 1. Frontal part of bus salon 3d-model

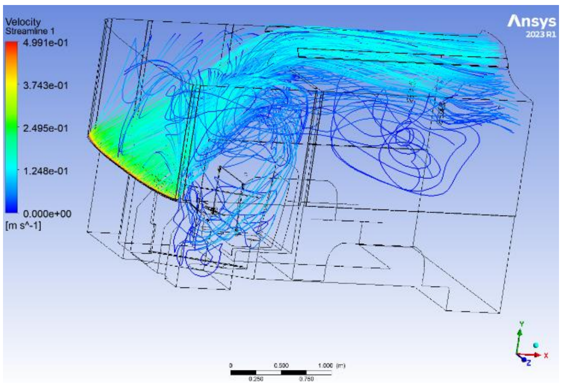

Figure 2. Distribution of air velocity

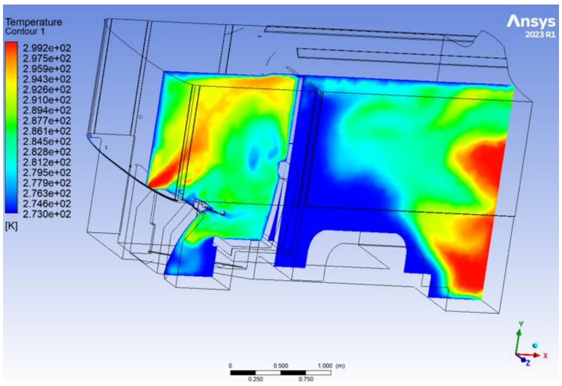

Figure 3. Temperature distribution

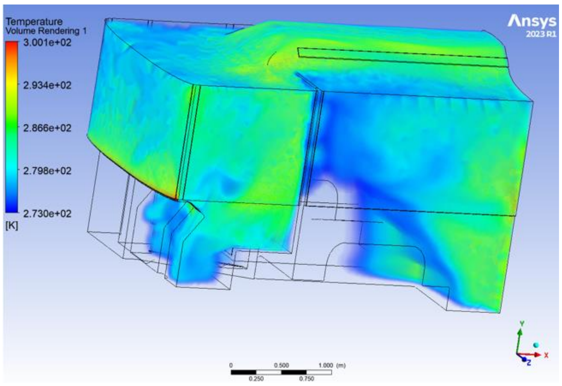

Figure 4. Distribution of air masses

Fig. 2 shows that the air flow comes out of the diffusers located next to the windshield of the bus with an air velocity of 0.5 m/s and a temperature of 27^{0}C. The air flow is directed upwards at an angle of approximately 45–50^0. As can be seen from fig. 2, the driver's head area will be heated the most, which it should be. Air flows are directed into the bus cabin, keeping to the upper part of the cabin with an air velocity 0.25–0.3 m/s. We see the intensive air circulation with a temperature of 18–20^{0}C at the level of the standing passenger's head in the front part of the bus cabin. The air flow swirls intensively in the area of the partition of the driver's cabin from the interior. The air velocity in this area decreases and will be approximately 0.15–0.2 m/s. That is, it turns out that in the zone of the driver's waist and legs, the air speed will vary between 0.1–0.15 m/s.

Analyzing the temperature maps (Fig. 3 and Fig. 4), it can be seen that the hottest air in the driver's cabin is at the level of the head, approximately +21–22^{0}C, and then gradually blows upwards with a drop in temperature to +18–21^{0}C. In the belt zone, the temperature ranges from +18–21^{0}C. The coldest area at the driver's workplace – the leg area. The temperature is in the range of 13–15^{0}C there.

Obtained results of temperature and velocity are demonstrated in Table 3.

Table 3

Calculation results of the driver's workplace microclimate

	Parameter	*Velocity, m/s*	*Temperature ^0C*
1	Head area	0,25–0,3	+21–22
2	Lumbar zone	0,1–0,15	+18–21
3	Leg area	0,1–0,15	+13–15

Conclusions. The calculation of microclimatic indicators at the driver's workplace showed that the temperature indicators during the operation of the heating system at the level of the driver's head and waist correspond to the norm. Air circulation in the driver's cabin occurs in such a way that part of the air enters the front part of the passenger compartment of the bus. This calculation method can be used for further scientific research in order to improve the bus heating system.

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МЕТОДИКА ТЕОРЕТИЧНОГО ДОСЛІДЖЕННЯ МІКРОКЛІМАТУ КАБІНИ ВОДІЯ АВТОБУСА ЗА ДОПОМОГОЮ ПРОГРАМНОГО СЕРЕДОВИЩА ANSYS-FLUENT

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Резюме. *Проаналізовано методику оцінювання забезпечення нормативно необхідних показників мікроклімату в кабіні автобуса та ризики, до яких може призвести їх недотримання. Серед основних ризиків зазначається вплив на самопочуття водія автобуса, в зв’язку з чим підвищується рівень появи ДТП. Оцінено проблеми забезпечення комфорту в салоні з економічної точки зору –комфортніший транспортний засіб зможе забезпечити вищий прибуток протягом експлуатації. Проведено аналіз наукових робіт вчених, що працюють у даній галузі як в Україні, так і за кордоном. Згідно з літературним оглядом бачимо, що тематика мікроклімату КТЗ активно розвивається у світі. Показано стан нормативної документації як в Україні, так і за кордоном, а також наведено приклади застосування нормативних значень параметрів мікроклімату. Додатково наведено основні проблеми, які наразі існують по нормативній базі в Україні та світі. За допомогою математичних залежностей описано теорію перенесення повітряних мас. Наведено можливості програмного середовища ANSYS, а також розглянуто, які поставлені задачі може вирішувати дане програмне забезпечення. Проведено розрахунки повітряних потоків у передній частині салону автобуса, зокрема у робочій зоні водія. Розрахунки проведено за допомогою програмного середовища ANSYS-Fluent, яке дає можливість моделювати процеси перенесення повітряних мас та визначати температурні карти салону автобуса. Згідно з результатами розрахунків встановлено значення швидкості повітря та температури в зонах робочого місця водія та в інших локаціях. Мікрокліматичні показники визначали в зоні голови водія, зоні поясу та ніг. З отриманих результатів випливає, що обдув лобового скла забезпечує достатню рівномірність розподілу повітряних мас по салону автобуса й може бути ефективно комбінований з іншими дифузорами системи вентиляції, що неодмінно може слугувати базою для наступних досліджень, спрямованих на підвищення показників мікроклімату автобусів.*

Ключові слова: *система опалення, мікроклімат, робоче місце водія, повітряні потоки, циркуляція повітря, FEA, температура повітря, швидкість повітря, температурний стан, ANSYS-Fluent.*

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