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Thermal comfort formation of the bus interior depending on the power unit layout

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Abstract

Energy consumption and thermal comfort are among the issues that research engineers of heating, ventilation and air conditioning systems deal with when investigating the most feasible solutions for their implementation. Existing methods of thermal comfort assessment are not optimized in two important and interrelated aspects: achieving thermal comfort (a) at the lowest possible energy consumption (b). Thermal comfort is situationally achieved when occupants perceive the ambient temperature, humidity, air movement and thermal radiation as ideal and do not prefer warmer or colder air or a different humidity level. Thermal comfort is defined by ASHRAE Standard 55 as a subjective concept characterized by the sum of sensations that create physical and mental well-being in a person. That is, he/she is in a state in which he/she feels comfortable and does not need to change one or more environmental parameters. Many studies have been conducted according to the international standards for thermal comfort in vehicles. The presence of a large number of people in the bus leads to a deterioration of the air quality in its interior. The loss of quality is mainly caused by gases resulting from breathing and other organic particles. The presence of moisture, combustion products, particles can also reduce the air quality in the interior. Air quality is affected by the design features of heating, ventilation and air conditioning systems, which largely depend on the location of the power unit, which is the subject of the research. The influence of the bus engine layout is analysed in the presented work: for the rear-engine layout, the location of the engine vertically in the interior and other cases are also considered. Special fans are installed in the engine compartment to remove heat emitted by the engine.

Key words: thermal comfort, ASHRAE Standard, EN ISO 7730, HVAC, heating, ventilation and air conditioning systems, engine placement, power unit layout, driver interior, passenger compartment, PMV, PPD indices.

Introduction

People spend a lot of time in public transport every day, for example, in buses, trams, trains or subways. To make their journey comfortable, appropriate thermal conditions must be provided by HVAC (Heating, Ventilation, Air Conditioning) systems. Thermal comfort is achieved when passengers perceive the air temperature, humidity, air movement, and heat radiation of their surroundings as ideal and would not prefer warmer or colder air or a different humidity level [1].

Current methods of assessing thermal comfort are not optimized following two crucial and interrelated aspects: achieving thermal comfort (a) with the lowest possible level of energy consumption (b). Actually, the energy consumption and thermal comfort are major concerns for research engineers in heating, ventilation and air conditioning systems, which are more or less feasible to implement solutions.

The purpose of the work

The purpose of the work was to investigate air flow distribution from the engine compartment, to analyse thermal comfort assessment in bus interior according the engine location (in case of different layouts).

Thermal comfort in transport

In fact, energy consumption and thermal comfort are major concerns for research engineers, studying solutions, which are more or less feasible to implement in heating, ventilation and air conditioning systems. For evaluating thermal comfort in the transport environment current standards which propose methods, are EN ISO 14505 and the American ASHRAE - 55. The first is divided into three parts. In ASHRAE 55 standard thermal comfort is defined by as a subjective concept characterized by a sum of sensations, which produce a person's physical and mental wellbeing, condition for which a person would not prefer a different environment. European EN ISO 7730 for assessing thermal comfort in buildings is used, based on the well-known theory of Fanger [2] and on the equivalent temperature model [3, 4]. EN ISO 7730 presents also the PMV and PPD indices proposed by Fanger over 30 years ago, Fanger conducted a study in which subjects that had "standard" clothes performing a “standard” activity.

In order to find an answer in terms of thermal comfort in vehicles many studies have been conducted following the three ways of approach the EN ISO 14505 [5] standards. Some of them take into account the subjective methods based on results collected from questionnaire surveys, others evaluate environmental quality based on experimental assessment of comfort parameters. In practice and in standards, in most cases, air temperature is the most observed and discussed of these parameters. A comfort value of the temperature is usually fixed inside the cockpit (interior) as main set point according to the outdoor air temperature.

Method to evaluate the thermal comfort as a function of air temperature is the one of the currently useds. This method uses sensors to measure local air temperature values at head and ankles level. The main purpose of this approach is to determine how quickly the temperature will increase or decrease in a warm or cold interior of the vehicle. It studies the non-homogeneity between the temperature at feet and head level and to establish if the global temperature level is situated within the limits of the accepted time. By using this method, only one of the needed parameters that concern the thermal comfort sensation is measured and any influence of air velocity and radiation (hot or cold) are neglected leading to wrong conclusions. This fact is a particularity of the thermal environment in vehicles where the air conditioning system leads to high local air velocities.

One of the principal factors of thermal discomfort both indirectly and directly is solar radiation, connected to the strong transient thermal regime. Kilic [6] recorded temperature values by 2°C higher in the case of sensors exposed to sunlight compared to those placed in the shaded zones, while a percentage between 18% - 31% of the cooling system capacity is used to reduce the load caused by the direct contribution of the solar radiation. The window colour is very important in this case. It can significantly reduce energy consumption for cooling by controlling the amount of fresh air introduced in the interior [7].

A fuzzy controller was used in study [8] in order to control two parameters - the air speed at the discharge grill and the percentage of recirculated air. By using the controller, it took less time to attain the desired interior temperature 20°C, which could be reflected on the energy consumption. Another method of reducing the fuel consumption of the vehicle is multi-zonal air distribution system. Conventional mono-zonal systems recorded an unnecessary energy consumption for cooling in the unoccupied space statistics show, if the vehicle has a low level of occupancy. Returning to the perspective of fuel consumption, authors investigated [9] the effect of the air-conditioning system. The effects obtained by reaching more efficient cooling around the occupants. The air distribution system was modified by installation discharge grills for rear passengers. The air being thus introduced through the discharge heaters from the dashboard for the front passengers, and ceiling discharge grills for the rear passengers. The PMV index was evaluated on base of computational fluid dynamics simulations correlated with empirical relations. The experimental validation of the simulations consisted in evaluating the performance of the air-conditioning system at various airflow rates and air temperatures. By the localized air-conditioning system, the energy was decreased by 20.8% and 30.2%, respectively, compared to a conventional situation [10, 11].

Another innovative air distribution system was studied [12] and concluded that in order to achieve the comfort parameters in the shortest time, the best place to install additional ventilation diffusers is behind the rear seat passengers. The authors found PMV index values between -0.3 and 0.2 during the warm season. Totally different from the values (-0.1 and 1) was obtained for situation without discharge heater behind the rear passenger’s seat. The authors noticed a non-uniformity between temperature exceeded 2°C, which measured at chest level between the front and rear parts of the vehicles.

In many cases parameters with an influence in assessing thermal comfort, actual thermal comfort indices solar radiation is not taken into consideration. This parameter does not only raise the indoor air temperature but is also a local discomfort parameter.

Implementing an anti-solar foil is a proven solution to reduce the solar radiation influence. But it has a negative influence on the driving safety during the night. Therefore, another solution is to implement local ventilation heater to reduce the energy consumption and to ensure a better uniformity for the indoor parameters of the interior.

The numerical calculation of airflow combined with heat exchange in a passenger coach was to carry out in [13]. Two cases of boundary conditions were considered with ANSYS CFX 12.1 software. The first obtained from design calculations common for ordinary buildings and information included in standards and the second was only based on the information included in standards. After analysing of the results, similar average air velocity was 0.79 m/s and it was found for distribution of air velocity in a coach in both cases. However, the distribution of air temperature was different. For case 1 the average indoor air temperature was 25.07°C and for case 2 was 23.53°C. The method of determining the heat solar gains had an impact on the results. A further possibility of a model improvement indicated that human models will be introduced in coaches, in order to verify the conditions of their thermal comfort, and air recirculation.

Bus power unit layout variants research

Since we propose the use of an additional fan, which is installed on the engine compartment, we should consider what options there are for the location of the engine in buses (possible layouts). There are shown the examples of buses with different engine locations (layouts) on Fig. 1 [14].

Fig.1 Buses with different engine layouts: a) front with a compartment in the interior; b) front with hood layout; c) middle horizontally under the floor; d) middle vertically; e) horizontally under the rear seats; f) rear vertically with an offset to the left.

The front-engine configuration is typical for small buses and minibuses. The layout of this type can be of two kinds. The first is with the location of the engine compartment in the bus interior at the front above the front axle (Fig. 1a). The driver usually has his own separate door built in. Buses of this type can be seen on the streets of Ukrainian cities, so-called "routes". The second kind has a hood layout (Fig. 1b) (typically for some brands of buses operated in the USA or some South American countries). American school bus is the most common variant of such bus, which is still manufactured today. Front-hood buses can be found in most cities of the world in the form of minibuses or small buses built on Mercedes Sprinter, Vario, etc. chassis.

The mid-engine layout is also not very popular today, even less popular than the front-engine one, and is characteristic only for some manufacturers (Volvo, Van Hool, MAZ). There are two types of such engine layout: under the floor (Fig. 1c) and vertically in a special section (Fig. 1d). It becomes impossible to create a 100% low floor interior when placing the engine under the floor or when placing the engine vertically, which is installed in areas for standing passengers. It is impossible to ensure a 100% low floor level but with such a scheme, that's why this type of layout could be met in two- or three-section buses.

Basically, the layout with the engine in the rear part is the most popular. There can be two options, when the engine is located under the rear seats (Fig. 1e) or when the engine is placed vertically in a special locker, which is shifted to the left (Fig. 1f).

Temperature state analysis in the bus interior

Thermal balance general equation of the bus interior will have the form [15]:

$$Q = \sum Q_i = Q_1 + Q_2 + Q_3 + Q_4 + Q_5, \quad (1)$$

where: Q_1 – infiltration of solar radiation; Q_2 – heat losses at service stops during the exit and entry of passengers; Q_3 – amount of heat coming through the surfaces of the bus body; Q_4 – amount of heat entering through the windows in the bus body; Q_5 – amount of heat emitted by passengers; Q – total amount of heat is needed to stabilize the temperature in the bus interior.

We consider heat transfer in stationary environment of constant density in the theory of thermal conductivity of materials, therefore the differential equation of thermal conductivity will have the form [16]:

$$a\left(\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2}\right)=\frac{\partial t}{\partial \tau}, \tag{2}$$

Based on the heat transfer equation (2), we need to find the temperature distribution over the volumetric body, taking into account the change in temperature t depending on the coordinates x, y, z in space and time τ.

The equitation (2) could be solved as a stationary one first. It is necessary to determine the initial conditions of the non-stationary problem in order to solve it (3):

$$\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2}=0, \tag{3}$$

We should consider our problem next as a flat heat conduction equitation, the general form of which will have such look (4):

$$\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}=0, \tag{4}$$

Let's reduce the final simplification of the problem (2) to the one-dimensional equitation of the thermal conductivity (5):

$$\frac{\partial^2 t}{\partial x^2}=0, \tag{5}$$

Such a equitation is further reduced to the calculation of the temperature distribution along the wall of thickness δ. The basic equation used in fluid and gas dynamics is the Reynolds-averaged Navier-Stokes. The speed in this case is divided into two components (6) [17]:

$$u_i=U_i+u_i', \tag{6}$$

where: U_i – the main component of speed; u_i' – the component of speed due to vibrations.

Instantaneous averaging over the Reynolds-averaged Navier-Stokes equation can be written as follows (7), (8) and (9):

$$\frac{\partial U_i}{\partial x_i}=0, \tag{7}$$

$$\rho\frac{\partial U_i}{\partial t}+\rho U_j\frac{\partial U_i}{\partial x_j}=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu(\frac{\partial u_i}{\partial x_j}-u_i u_j\right], \tag{8}$$

$$\rho\frac{\partial T}{\partial t}+\rho U_j\frac{\partial T}{\partial x_j}=-\frac{\partial}{c_p\,\partial x_j}\left(k\frac{\partial T}{\partial x_j}\right)-\frac{\partial u_i T}{\partial x_j}, \tag{9}$$

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

Since we are evaluating the heating elements efficiency, we should analyse the efficiency of the bus heating system. Let's evaluate the efficiency of the heating system using the exergetic efficiency (eq.10) with some correction factors taken into account:

$$\eta_{ex}=K_1K_2K_3\left(\frac{Ex_{sa}+Ex_{ea}}{Ex_{oa}+Ex_{ra}}\right), \tag{10}$$

where: K_1 - coefficient that depends on the location of the engine; K_2 - coefficient that depends on the season; K_3 is a coefficient that depends on the mode of operation of the bus on the route; Ex_{sa} – exergy of incoming air flow; Ex_{oa} – exergy of the external air flow; Ex_{ra} – exergy of air flow in the room; Ex_{ea} - exergy of the ejected air flow.

The next step of our work will be dedicated to study of the heat flow dissipation in the bus interior with different 5 variants of bus engine placement:

A - front;

B - middle vertically;

C - middle horizontally with an opposite engine;

D - rear vertically shifted to the left;

E - rear horizontally with an opposed engine.

Basically, the temperature values on the walls that separate the engine from the passenger compartment are approximately 30-50 ^{0}C. Knowing this, we can now set the initial parameters (Table 1) to calculate and simulate the temperature distribution in the Ansys Fluent Flow software environment [18, 19] for those five different bus layouts.

Table 1

Boundary conditions for air flow modelling in the bus interior

#	Parameter	Unit	Meaning
1	Gravity	m/s^2	-9.81
2	Velocity magnitude (inlet area)	m/s	0,25
3	Temperature (inlet area)	K	318
4	Temperature of internal volume and walls	K	293
5	Convection for static air	W/m^{2}K	25

We will additionally use special fans, which are installed on the engine compartment regardless of its location, and serve to transfer the heat released by the engine during its operation and disperse this heat throughout the bus interior.

The calculation method should be explained first. We have designed 3D models of bus interior spaces with air intake and exhaust locations to achieve our goals. Having the necessary models, FEA mesh was generated for the appropriate models for applying of the boundary conditions. The next step was to set up the solution and run the simulation to obtain the results of the calculations.

The vast majority of real liquid or air flows will pass in a turbulent mode [20 – 22], because they carry out non-uniform movement in the required areas. We perform calculations on a simplified model of a city bus in our study - that is, we have a 3D model of the bus with only those elements that we need in the calculations, namely the elements of the internal space of the bus. Total calculation time on the equipment (2 Intel Xeon processors 24 cores, RAM 48 Gb, NVIDIA GeForce 4Gb video) was 6 hours 17 min. Later we consider the results of modelling temperature flows in bus interiors with different engine layouts.

Taking into account the fact that microclimatic parameters are standardized at three levels (floor, middle and head) in many regulatory documents, we will also further consider the distribution of temperatures in these zones as shown in fig. 2. We divided the interior of the bus into 6 zones: 3 horizontally (floor, middle and head level) and 3 vertically (driver's interior, middle storage and rear platforms).

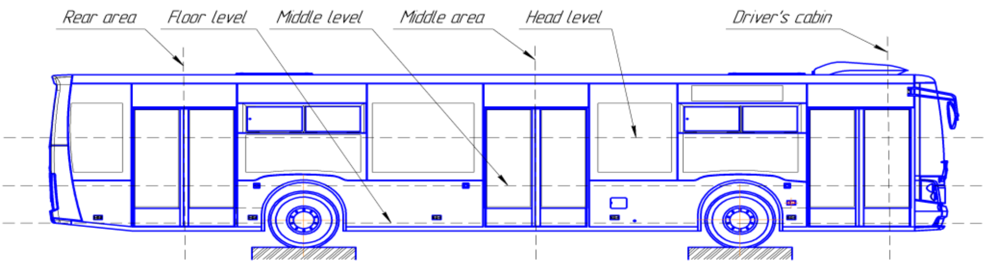


Fig. 2. Zones of the bus interior

Heat flow modelling – front layout (A)

As we can see in Fig. 3a, the air flows come out of the engine compartment from the front near the driver's workplace and then disperse throughout the bus interior. Air flows intensively at the level of the feet with temperature fluctuations in the region of 25^{0}C at the driver's workplace. Next, the air flow is dispersed throughout the interior, keeping to the floor level. The air speed at floor level is approximately 0.18-0.19 m/s. The temperature fluctuates at the level of 18-20^{0}C (Fig. 5b and 5c) in this area. As you can see, the air circulation is not very active, because the distribution of air is somewhat limited, due to the fact that a wider flow of air is hindered by the wheel arches and the fact that the air is blown lower, closer to the floor. In principle, there is no air circulation in the driver's interior. One plane is chosen at the level of the seats of the left row (Fig. 3b), and the second - in the middle of the interior (Fig. 3c). As it can be seen from Fig. 3 the hotter air is expected at floor level between the front wheel arches and the temperature in this area is approximately 20-25^{0}C. To visualize the air stream velocity we have used 300 lines modelling (Fig. 1a) – it's optimum meaning to show the situation inside of interior properly: more lines will fill the space with indistinguishable flows; less meaning will steal important information about the flow's behavior (where and how the air flows are getting and spreading inside). The highest speed of the air flow correspondents to the closer to red color and is observed near the inlet and outlet channels (both are working as funnels). The same approach with 300 lines modelling is used for all the rest calculation cases presented below.

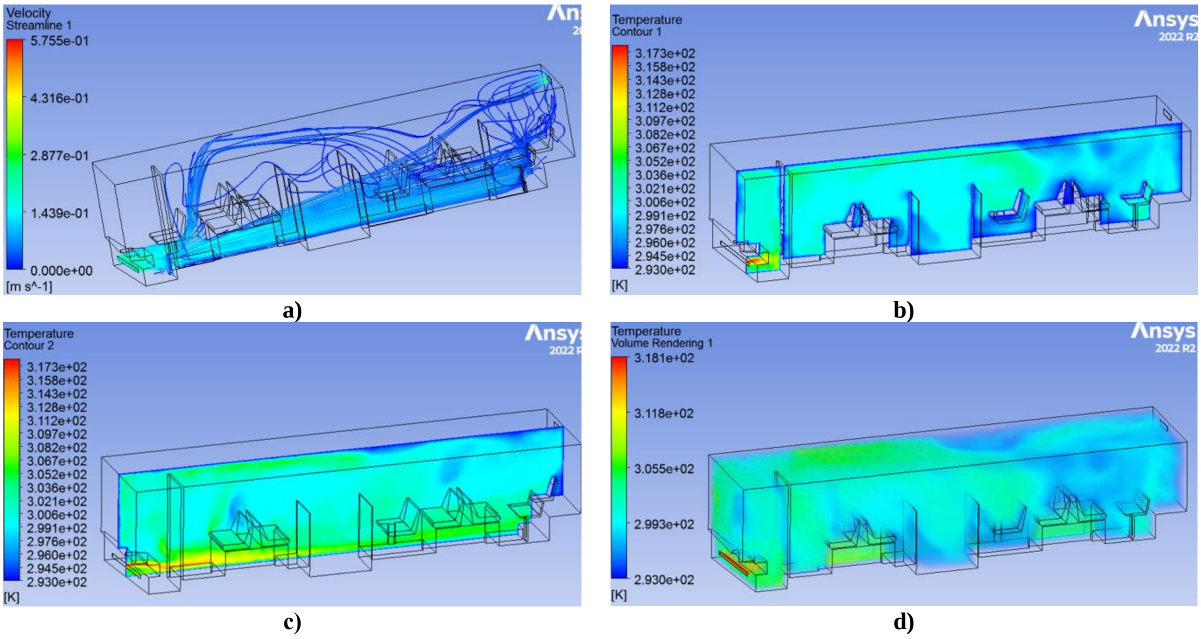


Fig. 3. Velocity and temperatures distribution in the interior with a front layout: a) velocity in the interior; b) temperature distribution along the plane at the level of the left row of seats; c) temperature distribution along the plane at the level of the middle of the interior; d) temperature maps of the interior volume

Heat flow modelling – middle vertically layout (B)

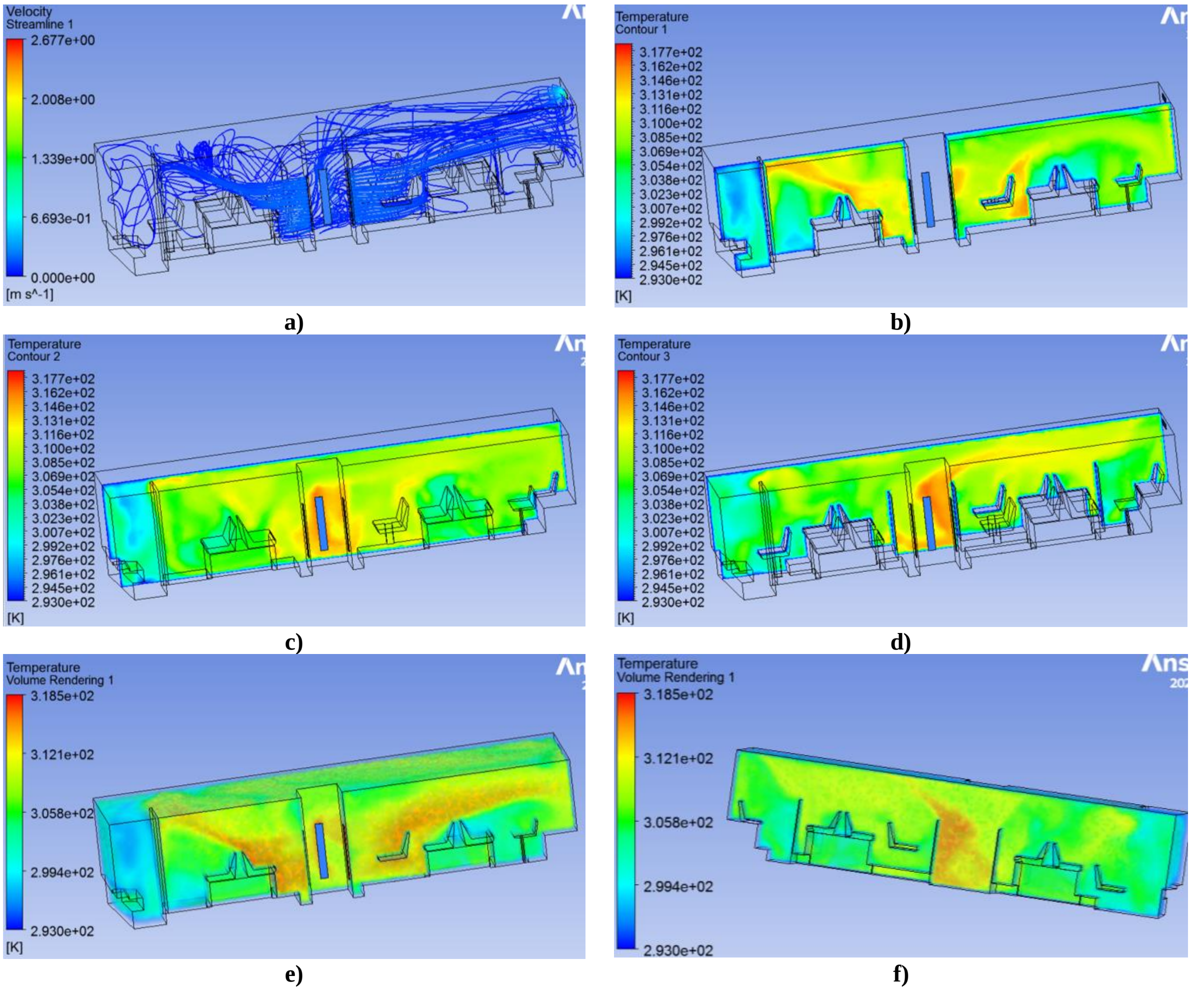


Fig. 4. Velocity and temperature distribution in the interior with a middle vertically layout: a) velocity in the interior; b) temperature distribution along the plane at the level of the left row of seats; c) temperature distribution along the plane at the level of the middle of the interior; d) temperature distribution on the plane at the level of the right row of the interior; e), f) temperature maps of the interior volume

Air flows were simulated in the middle vertically engine layout, taking into account the fact that three additional fans are installed in the middle of the engine compartment, so there are three places for blowing warm air. As we can see in Fig. 4a, the air flows from the places where warm air is blown into the engine compartment in three different directions (left to the front, right to the back, and straight towards the middle door). It can be seen that the air flows intensively disperse in places of the interior to the wheel arches at a height of approximately 1.5 m from the floor level with a speed somewhere at the level of 0.2-0.25 m/s with a temperature of approximately 25-27 ^{0}C (Fig. 4a). There are almost no air flows in the driver's interior. Air speed and temperature in the driver's interior are 0.2-0.25 m/s and 18-20 ^{0}C, respectively. This happens due to the fact that the driver's interior is separated from the interior space. Next, the air flow is dispersed throughout the interior. The highest temperature values are reached at the storage site and are 27-28 ^{0}C. As you can see, the air circulation is very active, since the air distribution comes from 3 points and is directed in different directions. The average air speed in the interior is 0.2-0.25 m/s. We choose the first plane at the level of the seats of the left row (Fig. 4b), the second in the middle of the interior (Fig. 4c) and the third - at the level of the seats of the right row (Fig. 4d). The highest temperature values are reached at the storage site and are 27-28 ^{0}C. As it can be seen from Fig. 4e and 4f, hotter air is assumed at the level of the seats near the engine compartment and, accordingly, is dispersed upwards in the space of the bus interior with a temperature of 25-27 ^{0}C. Looking at the temperature maps, it's clear that the passenger compartment is heated better than the driver's interior.

Heat flow modelling – middle horizontally with an opposite engine layout (C)

Air flows were simulated, taking into account that two additional fans are installed on the left and right walls on the floor (opposite engine compartment). It turns out that there will be two places for blowing in the middle of the bus interior.

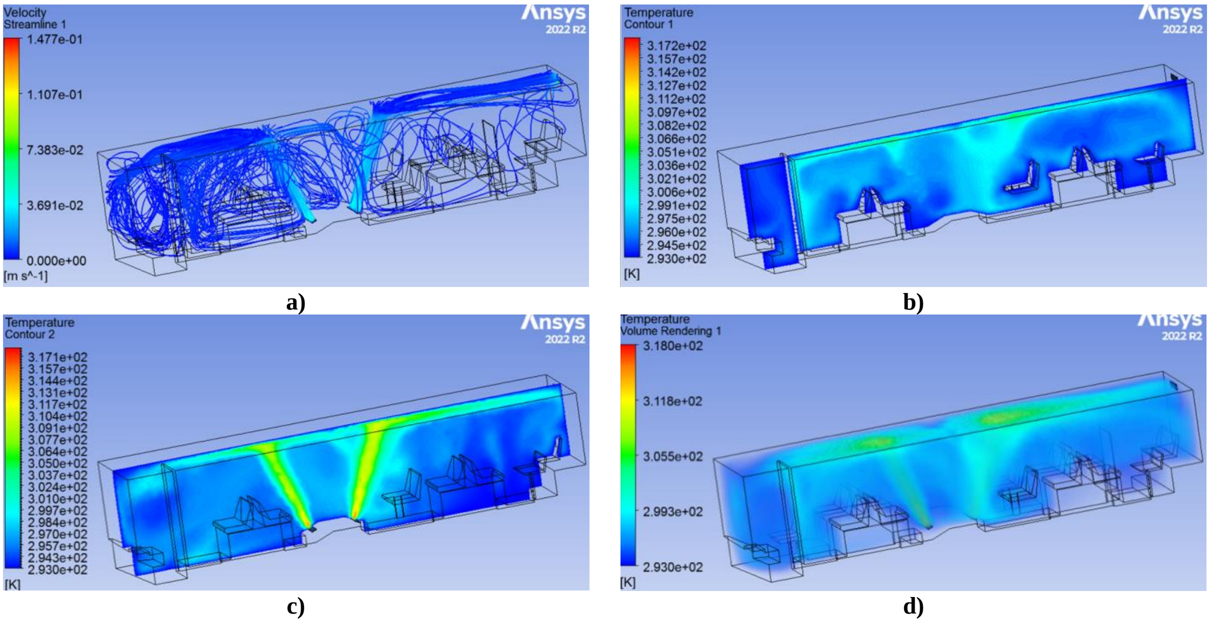


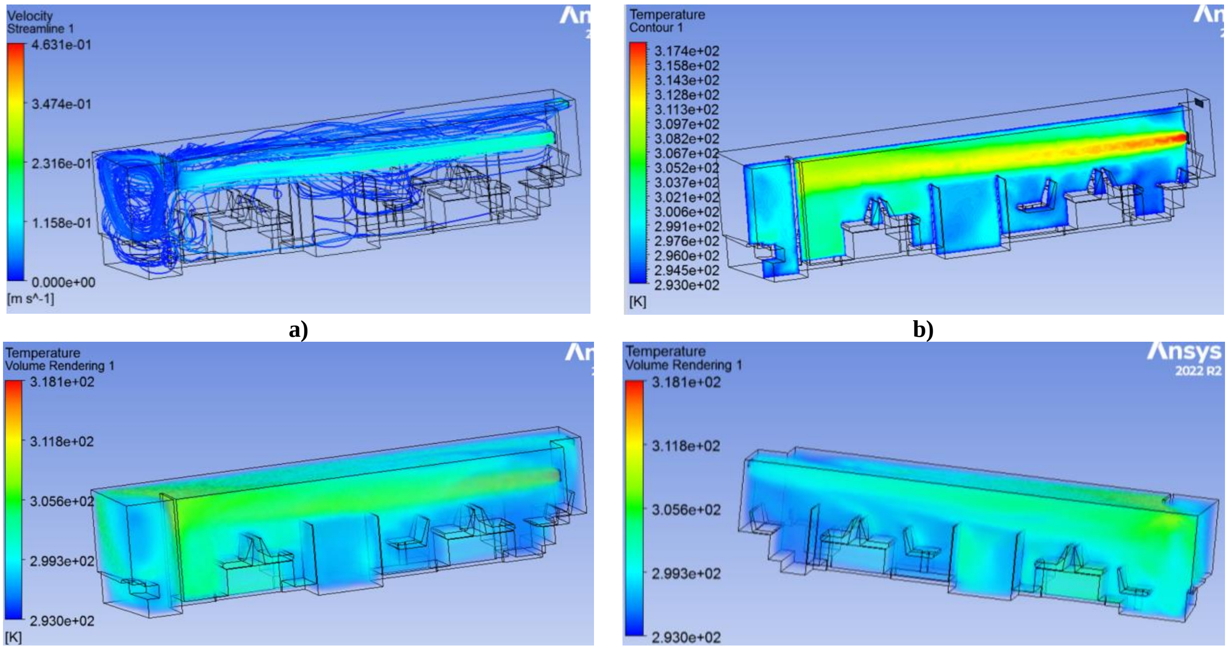
Fig. 5. Velocity and temperature distribution in the interior for middle horizontally with an opposite engine layout: a) velocity in the interior; b) temperature distribution along the plane at the level of the left row of seats; c) temperature distribution along the plane at the level of the middle of the interior; d) temperature maps of the interior volume

As we can see in Fig. 5a, the air flows from the warm air outlets on the engine compartment, which in our case is also the part of the floor, in two different directions (left up and right up) and disperse at the ceiling level. Air circulation occurs at a speed of approximately 0.2-0.25 m/s at head level. It can also be seen that the air flows are intensively dispersed in the front part of the bus and also enter the driver's interior, where the air speed is at the level of 0.2 m/s. As you can see, air circulation is very active in the driver's interior and the front part of the bus interior. In the rear part of the bus, air flows circulate in smaller quantities than in the front part.

We choose the first plane at the level of the seats of the left row (Fig. 5b) and the second - in the middle of the interior (Fig. 5c). The temperature fluctuates almost uniformly throughout the bus interior in the region of 14-16 ^{0}C, which is a fairly comfortable microclimate. Hotter air is expected in places along the flow of hot air from the fans and dissipates accordingly upwards (Fig. 5C). The temperature is around 20 ^{0}C at head level in such locations.

Heat flow modelling – rear vertically shifted to the left layout (D)

Air flows were modelled taking into account that the additional fan is located on the wall of the engine compartment above the last two seats in the left row of bus seats.



a) b) c) d)

Fig. 6. Velocity and temperature distribution in the interior with rear vertically shifted to the left layout: a) velocity in the interior; b) temperature distribution along the plane at the level of the left row of seats; c), d) temperature maps of the interior volume

Air flows from the warm air outlet on the engine compartment above the seats in the rear part of the bus interior (Fig. 6a). It is clearly visible that the air flows intensively disperse above the bus interior with an air speed of Fig. 6a, approximately at the level of the standing passenger’s head, and also enter the driver’s place due to the fact it is not tightly separated from the interior. The speed of air flow in this area is 0.15-0.22 m/s. We choose the plane at the level of the seats of the left row (Fig. 6b). The temperature fluctuates in the area in most of the interior is around 18-20 ^{0}C, only in the rear part in the area of the thermal air outlet it reaches 22-24 ^{0}C.

Heat flow modelling – rear horizontally with an opposed engine layout (E)

An additional fan is located on the wall of the engine compartment below at the level of the feet for the presented case. Air flows come from the warm air outlet on the wall of the engine compartment under the seats in the back of the bus interior (Fig. 7a) and intensively dispersed around the interior by turbulent flows at a speed of **0.18-0.2 m/s**, and also enter the driver’s interior with the low speed **0.17-0.18 m/s** due to the fact that that the driver's place is not tightly separated from the rest of the interior volume.

The plane is chosen at the level of the seats left row (Fig. 7b) and at the level of the middle of the interior (Fig. 7c). The highest temperature values are in the rare part of the bus at the level of the legs and waist are **24-28 ^{0}C**. Further, the temperature drops in the interior, it will reach **18-22 ^{0}C** in the middle of the bus and **18-20 ^{0}C** in the driver's interior.

After analysing the obtained results, we will compile data in tables with temperatures and air velocities for the researched 5 layouts different of the bus (Table 2, 3). It must be admitted that the air dispersity depends much of the convection for static air inside of the interior: either the conditioning system is activated and blows actively or the windows are opened which could be possible during the warm season of the bus exploitation. Being said the research experiments presented in the current publication were based on 25 W/m^{2}K (Table 1). Minimal convection of the static air could be 5 W/m^{2}K (typical) for the real-life buildings, etc, but the presence of a large number of people in the bus leads to a deterioration of the air quality in its interior. The loss of quality is mainly caused by gases resulting from breathing and other organic particles, so the convection should be raised however to 25 W/m^{2}K to achieve the necessary refreshing of the air volume. On another hand stays the fan speed, which is variable (was set 0.25 m/s in our boundary conditions) and could be increased by necessity. Should it help for the circulation and comfort? Well, it depends on the bus layout: for example, the increasing the fan speed for rear vertically shifted to the left layout (D) won’t be efficient – the air stream will just pass faster near the passenger’s heads, but less its portion will be renewed on the middle and especially floor level!

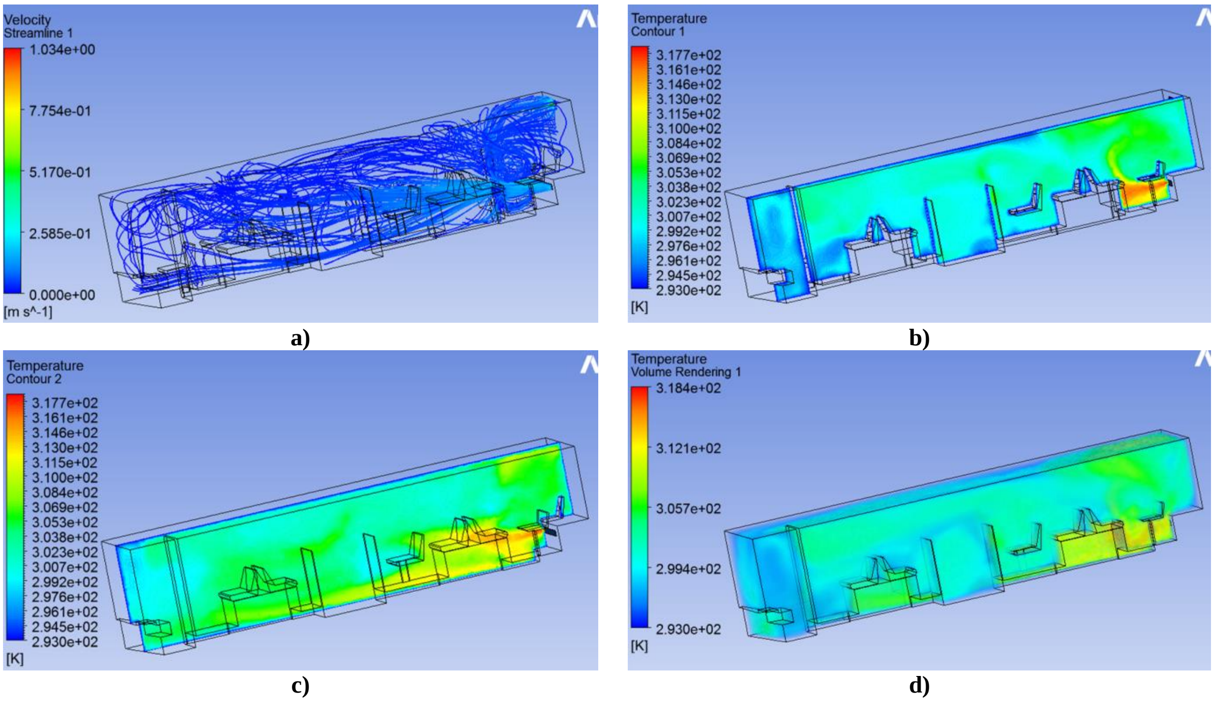


Fig. 7. Velocity and temperature distribution in the interior for rear horizontally with an opposed engine layout: a) velocity in the interior; b) temperature distribution along the plane at the level of the left row of seats; c) temperature distribution along the plane at the level of the middle; d) temperature maps of the interior volume

Table 2

Temperature parameters in the bus's interior depending on the power unit layout

#	Power unit layout	Interior level	Driver's interior, m/s	Middle area, m/s	Rear area, m/s
1.	A)	floor	25	18-20	18-20
2.		middle	19-20	18-20	14-20
3.		head	18-20	18-20	14-20
4.	B)	floor	18-20	25-27	18-20
5.		middle	18-20	27-28	18-20
6.		head	18-20	27-28	20-21
7.	C)	floor	14-16	14-16	14-16
8.		middle	14-16	14-16	14-20
9.		head	14-16	18-20	14-20
10.	D)	floor	18-19	19-20	14-16
11.		middle	18-19	19-20	16-18
12.		head	19-20	20-22	22-24
13.	E)	floor	18-20	19-22	26-28
14.		middle	18-20	19-22	24-25
15.		head	18-20	19-22	20-22

Table 3

Air velocity in the bus's interior depending on the power unit layout

#	Power unit layout	Interior level	Driver's interior, m/s	Middle area, m/s	Rear area, m/s
1.	A)	floor	0,2	0,18-0,19	0,1-0,15
2.		middle	0,05	0,18-0,19	0,1
3.		head	0,02	0,05	0,05
4.	B)	floor	0,2	0,2-0,25	0,2-0,25
5.		middle	0,2-0,25	0,2-0,25	0,2-0,25
6.		head	0,2-0,25	0,2-0,25	0,2-0,25
7.	C)	floor	0,2	0,2-0,25	0,2
8.		middle	0,2	0,2-0,25	0,2
9.		head	0,2	0,2-0,25	0,2
10.	D)	floor	0,18-0,19	0,15	0,2-0,25
11.		middle	0,18-0,19	0,15	0,2-0,25
12.		head	0,18-0,19	0,15	0,2-0,25
13.	E)	floor	0,17-0,18	0,18-0,2	0,2-0,25
14.		middle	0,17-0,18	0,18-0,2	0,2-0,25
15.		head	0,17-0,18	0,18-0,2	0,2

Conclusions

FEA computer modelling in engineering or scientific development is very important nowadays, because we can get the preliminary results of our work and its shortcomings with the help of specialized software, which will allow to eliminate problems much faster in the future without live tests. Boundary conditions and the designed calculation approach are the keys to create maximum similar to the real-life results and environment methodology, which will be accurate and efficient enough to imitate the bus interior air flow.

It was proposed to add an additional fan, which will be attached to the engine compartment, and the outlet channel on the rear wall of the bus. By using computer simulation carried out in the ANSYS Fluent Flow software environment the results of the calculation showed that the temperature with 5 different layouts of the interior remains within the normal range of approximately 296-305 K, but differs significantly by the locations. The best circulation of air flows occurs with the following layouts of the engine in the bus: middle vertically and rear horizontally with an opposite engine. Such schemes are the most efficient due to the balance of temperature vs velocity distribution and final microclimate comfort inside of interior.

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Голенко К.Е., Войчишин Ю.В., Горбай О.З., Бур'ян М.В., Попович В.В., Маковкін О.М.
Формування теплового комфорту салону автобуса в залежності від компоновки силового агрегата

Енергоспоживання та тепловий комфорт належать до проблематики, якою займаються інженери-дослідники систем опалення, вентиляції та кондиціювання повітря при пошуку рішень, найбільш можливих для їх реалізації. Існуючі методи оцінки теплового комфорту не є оптимізованими за двома важливими і взаємопов'язаними аспектами: досягнення теплового комфорту при мінімально можливому рівні енергоспоживання. Тепловий комфорт ситуативно досягається тоді, коли пасажири сприймають температуру, вологість, рух повітря та теплове випромінювання навколишнього середовища як ідеальні і не надають перевагу більш теплому чи холодному повітрю або іншому рівню вологості. Тепловий комфорт визначається стандартом ASHRAE 55 як суб'єктивне поняття, що характеризується сумою відчуттів, які створюють у людини фізичне та психічне благополуччя: вона перебуває в стані, за якого почуває себе комфортно і не потребує зміни одного чи декількох параметрів навколишнього середовища. Було проведено багато досліджень за міжнародними стандартами щодо теплового комфорту в транспортних засобах. Присутність великої кількості людей в автобусі приводить до погіршення якості повітря в його салоні. Втрата якості в основному викликана газами, що утворюються в результаті дихання та виходу інших органічних частинок. Наявність вологи, продуктів згоряння, частинок також може знизити якість повітря в салоні. На якість повітря впливають і конструктивні особливості систем опалення, вентиляції та кондиціювання повітря, які в значній мірі залежать від розташування силового агрегату, що і є предметом проведених п'яти досліджень. Проаналізовано вплив розташування двигуна міського автобуса спереду, в базі та в задній частині на зміну повітрообміну в салоні. Для задньомоторної компоновки розглянуто також розташування двигуна вертикально в шафі-тумбі. Для відбору теплоти, яка виділяється двигуном у мотовідсіку встановлено спеціальні вентилятори.

Ключові слова: тепловий комфорт, ASHRAE, EN ISO 7730, HVAC, опалення, вентиляція та кондиціонування повітря, розташування двигуна, кабіна водія, пасажирський салон, PMV, PPD.