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PREDICTION OF MICROCLIMATE NEAR SMALL ARCHITECTURAL CONSTRUCTIONS

Создана математическая модель для прогнозирования параметров микроклимата в рабочей зоне, находящейся непосредственно вблизи автомагистрали при наличии «временного сооружения» и при его отсутствии. Разработана численная модель для определения поля скорости воздушного потока в зоне нахождения работника с учетов расположения выносного места торговли, «временного сооружения» без навеса и с навесом на основе уравнения Навье-Стокса. Для прогнозирования уровня концентрации в микрозоне использовано двухмерное уравнение переноса примеси в атмосферном воздухе. Численное интегрирование уравнений

гидродинамики и масопереноса выполнено с помощью неявной разностной схемы. Рассмотрены три варианта расположения места торговли в зоне влияния автомагистрали: первый вариант – продавец выполняет торговлю выносным товаром без наличия «временного сооружения»; второй вариант – продавец выполняет торговлю выносным товаром у «временного сооружения», которое не имеет навеса; третий вариант – продавец выполняет торговлю выносным товаром у «временного сооружения», имеющего навес. Проведен анализ изменения скорости воздушного потока и концентрации загрязнителя на уровне расположения головы работника (локально) в зависимости от варианта расположения места торговли. Наличие «временного сооружения» уменьшает скорость в 2 раза и концентрацию 1,5 раза, наличие навеса в том же сооружении уменьшает скорость в 5 раз и концентрацию в 1,75 раза, относительно ситуации, когда навес отсутствует. Выявлено, что навес влияет на изменение концентрации загрязнителя, но играет более значительную роль для уменьшения скорости воздушного потока, обеспечивая комфортные условия микроклимата в рабочей зоне. Длительное или систематическое пребывание в такой рабочей зоне не будет отражаться на состоянии работающего, может обеспечивать его высокую работоспособность и комфорт пребывания в рабочей зоне.

Ключевые слова: рабочая зона, микроклимат, «временное сооружение», поле скорости, концентрация загрязнителя.

Створено математичну модель для прогнозування параметрів мікроклімату в робочій зоні, що знаходиться безпосередньо поблизу автомагістралі при наявності «тимчасової споруди» та при її відсутності. Розроблено числову модель для визначення поля швидкості повітряного потоку в зоні знаходження працівника з урахуванням розташування виносного місця торгівлі, «тимчасової споруди» без піддашку та з піддашком на основі рівняння Нав'є–Стокса. Для прогнозування рівня концентрації в мікрозоні використано двомірне рівняння переносу домішки в атмосферному повітрі. Чисельне інтегрування рівнянь гідродинаміки та масопереносу виконано за допомогою неявної різницевої схеми. Розглянуто три варіанти розташування місця торгівлі в зоні впливу автомагістралі: перший варіант – продавець виконує торгівлю виносним товаром без наявності «тимчасової споруди»; другий варіант – продавець виконує торгівлю виносним товаром біля «тимчасової споруди», що не має піддашку; третій варіант – продавець виконує торгівлю виносним товаром біля «тимчасової споруди», що має піддашок. Проведено аналіз зміни рівня швидкості повітряного потоку та концентрації забруднювача на рівні розташування голови працівника (локально) в залежності від варіанту розташування місця торгівлі. Наявність «тимчасової споруди» зменшує швидкість у 2 рази і концентрацію в 1,5 рази, наявність піддашку зменшує швидкість у 5 разів і концентрацію в 1,75 рази, відносно ситуації, коли піддашок відсутній. Виявлено, що піддашок впливає на зміну концентрації забруднювача, але відіграє значну роль для зменшення швидкості повітряного потоку, забезпечуючи комфортні умови мікроклімату в робочій зоні. Тривале або систематичне перебування в такій робочій зоні не відбивається на стані здоров'я працівника і може забезпечувати його високу працездатність і комфорт перебування в робочій зоні.

Ключові слова: робоча зона, мікроклімат, «тимчасова споруда», поле швидкості, концентрація забруднювача.

A mathematical model has been created for predicting the microclimate parameters in the work area located directly near the motorway in the presence of a «temporary building» and in its absence. A numerical model has been developed to determine the velocity field of the air flow in the area of employee's location, taking into account the location of the remote trading place, the "temporary building" without an eaver and with an eaver based on the Navier–Stokesequation. To predict the concentration level in the microzone, two-dimensional equation of impurity transport in atmospheric air is used. Numerical integration of the equation of hydrodynamics and mass transfer is carried out with the help of an implicit difference scheme. Three variants of the location of trading place in the zone of motorway influence are considered: the first option – the seller performs the trade of outbound goods without the presence of a "temporary building"; the second option is that the seller performs the trade of outbound goods at the"temporary building", which does not have an eaver; the third option is that the seller carries out the trade of outbound goods at the"temporary building", which has an eaver. The analysis of changes in airflow velocity and concentration of pollutant at the level of the head of employee (locally), depending on the location of the place of trade. The presence of a "temporary building" reduces the speed by 2 times and the concentration by 1.5 times, the presence of an eaver in

the same structure reduces the speed by 5 times and the concentration by 1.75 times, relative to the situation when the eaver is absent. It has been revealed that the eaver influences the change in pollutant concentration, but plays more significant role in reducing the speed of the air flow, providing comfortable conditions for the microclimate in the work area. Long or systematic stay in such a work area will not affect the worker's state of health, can ensure its high performance and comfort in the working area.

Key words: working area, microclimate, «temporary building», speed field, concentration of pollutant.

Problem statement and analysis of publications. Microclimate is a combination of atmospheric air parameters that affect the human body: temperature, humidity, air velocity and thermal radiation of heated surfaces. The microclimate is characterized by a number of features inherent in limited spaces, it can vary at a distance of several dozens or even hundreds of meters. The microclimate of the city, quarter, street, park affects the body, health and human health. The state of human health is known to be an indirect indicator of the environment state. The pollution of any environment is unfavorable for a person. If it is considered that people consume more than 9 kg of air per day, then the pollution of air is the most harmful to its health. In this regard, respiratory diseases are the most significant in all countries of the world. The microclimate of the city is characterized by the complication of air circulation, even if the streets of the city are planned in the direction of the prevailing winds. The air temperature is much higher than in the neighboring rural areas. The system of city streets and squares leads to changes in the direction of the wind in the city. The wind is mostly along the streets. In general, the wind speed in the city weakens, but in narrow streets is intensified; on the streets and crossroads there are easy dust vortices.

Road transport pollutes city air most of all. With a steady stratification of the atmosphere, especially with temperature inversions, smoke and dust can accumulate in the surface layer of the atmosphere in an amount that adversely affects human health.

The microclimate of cities is different from the climate of the surrounding area due to stone and asphalt roads and high buildings that heat and radiate heat (the average annual temperature in the city is higher by 1–3°C, and the relative humidity is lower by 10–15%). The rising streams over the city cause an inflow of cool air in a quiet weather from the periphery to the center. Multi-storey buildings reduce the wind speed twice. The atmospheric air pollution reduces the solar and ultraviolet radiation to 20–50%. Natural greenery reduces the influence of wind, the effect of industrial and transport pollution and noise, releases phytoncides, oxygen into the air, supply clean air to the urban environment.

The location of roads and buildings, the parameters of atmospheric air – factors that contribute to the changing microclimate of the city. In the terms of a spectacular market economy, there is an increase in «temporary buildings», namely, the construction of a commercial, household, socio-cultural or other purpose for entrepreneurial activity. «Temporary building» is a one-story building, which is made of lightweight constructions according to the technical regulation of constructions, buildings that are established temporarily without the arrangement of the foundation: kiosks, stops, pavilions. Most of them are located along the city highways, at stops where employees sell different types of goods. Work on the street near the road is unfavorable for people, because the inflow of harmful emissions of vehicles, the presence of significant wind speed negatively affects the body, health of workers.

As a result of the reconstruction of «temporary building», the appearance of new and disappearing of others changes the aerodynamic mode of flow and violates the parameters of the microclimate. It is important to be able to perform forecasting in order to take measures regarding the provision of standard comfort parameters. There is a question regarding the simulation of comfort conditions for workers located near highways, taking into account two factors: gas pollution and air comfort in the working area. Simulation is performed on a microscale.

In foreign works, environmental parameters and methodology of analysis are considered, which is aimed at creating a bioclimatic strategy for buildings based on components of geometry and the quality of material surfaces, depending on the microclimatic conditions. In addition, it is noted that microclimate parameters are of great importance for outdoor activities [1]. Work is carried out on the study of the impact of residential buildings on the boundary conditions of the microclimate in different regions of the city [2], the impact of urban microclimate on the thermal comfort in buildings [3], the impact of air load on the building and changes in the microclimate due to different location and different height of buildings, which leads to the formation of vortices of different power [4]. The second set of studies relates to the study of microclimate in enclosed premises in the work areas of various specific activities. All studies are conducted either through experiments or as part of numerical modeling of air processes and loads, pollution dispersal, performed in SolidWorks software packages, COMSOL Multiphysics, ANSYS, where various numerical simulations are used. In this regard, the problem of developing a numerical model and a complex of calculation programs that allow to calculate the air velocity field to find the distribution of the pollutant concentrations not only in the zone of the «temporary building», but also locally, at the level of the respiratory organs of the worker.

Formulating the purpose of writing an article. The purpose of the article is to forecast the parameters of the microclimate, simulate the conditions of comfort for workers located within the «temporary building» location, studying the impact of the barrier and the subassembly of the structure itself on the level of wind speed and concentration of pollution.

Presenting of main material. To determine the speed field, it is proposed to use a model based on the Navier–Stokes equation written in the Helmholtz variables:

$$\frac{\partial \omega}{\partial t}+\frac{\partial u\omega}{\partial x}+\frac{\partial v\omega}{\partial y}=\frac{1}{\mathrm{Re}}\left(\frac{\partial^2\omega}{\partial x^2}+\frac{\partial^2\omega}{\partial y^2}\right), \tag{1}$$

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}=-\omega, \tag{2}$$

where $\mathrm{Re}=\frac{V_0 L}{\nu}$ – the Reynolds number; ν – the kinematic viscosity coefficient; ψ – the current function; $\omega=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}$ – the vortex; $u=\frac{\partial \psi}{\partial y}$, $v=-\frac{\partial \psi}{\partial x}$ – the components of the velocity vector of the air flow; L – the characteristic linear size; V_0 – the characteristic velocity of the air flow.

Using the Navier–Stokesequation in this form allows to exclude the calculation of the pressure field from the solution [5, 8].

The initial and boundary conditions for equations (1) – (2) are as follows:

– on the solid walls the condition of adhesion is placed $\psi|_{\gamma} = const,\ \frac{\partial\psi}{\partial n} = 0$;

– at the entrance to the calculated area a profile of speed $u = f(y)$ and the corresponding value of the current function $\psi|_{\gamma} = const$ are set;

– at the entrance of the calculated area the vorticity $\omega = 0$;

– at the initial bound is placed a "soft" boundary condition for the function of current and vibrationalities $\left.\frac{\partial\psi}{\partial n}\right|_{x=L} = 0$, where L – the boundary of the calculated area;

– at the initial moment $t = 0$ for the vorticity $\omega|_{t=0} = 0$.

The methodology [8] is used to determine the vorticity on solid walls (boundaries).

One of the important parameters of the microclimate is the content of the pollutant in the microzone, for prediction the 2D model of the mass transfer equation is used:

$$\frac{\partial C}{\partial t} + \frac{\partial uC}{\partial x} + \frac{\partial(v - w_s)C}{\partial y} = \frac{\partial}{\partial x}(\mu_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(\mu_y \frac{\partial C}{\partial y}) + \\ + \sum Q_i \delta(x - x_i)(y - y_i), \quad (3)$$

where C – concentration of pollutant; u, v – components of the velocity vector of air flow; w_s – velocity of gravitational settling of polluting substance; $\mu = (\mu_x, \mu_y)$ – coefficients of turbulent diffusion; (x_i, y_i) – coordinates of the pollutant release source; Q_{i} – intensity of the pollution source at the point; $\delta(x - x_i)(y - y_i)$ – Dirac delta-function. Profile of wind speed at the entrance to the calculated area $u = u_1\left(\frac{Y}{Y_1}\right)^n$, where u_1 – the value of wind speed at altitude Y_1; state of the atmosphere (inversion, convection), the value of the vertical diffusion coefficient $\mu_y = k\left(\frac{Y}{Y_1}\right)^m$, $k = 0{,}2$, $m \approx 1$ [7].

An implicit alternating-triangular difference scheme and boundary conditions are used for the numerical integration of the vorticity transfer equation (1), which describes the flow of viscous fluid and the mass transfer equation (3) [6]. It is constructed on a rectangular spaced net: the current function is determined in its nodes, the vortex is in the centers of the difference cells, the component of the velocity u – on the vertical, component of the velocity v – on the horizontal sides of the difference cells, the concentration C is determined in the center of the difference cells [8]. For the numerical integration of the Poisson equation (2), the iteration method is used, while the vorticity ω in the cells adjacent to solid walls, where the condition $\left.\frac{\partial\psi}{\partial n}\right|_{x=L} = 0$ is used, function ω is determined only in internal difference cells. In the framework of the accepted mathematical model, the structure of the flow in the studied region is affected by perturbations outside the calculated region, so we assume that perturbation at the input and output limits of the region can not be propagated by diffusion, the number of Reynolds $Re \to \infty$ for air flow outside the calculated region.

In the numerical model, the modeling of the real position of the employee in the form of a plate, a remote place of trade and the presence of the product itself, which is a typical situation in small cities near the highway in the absence and presence of a temporary construction at a place of trade is carried out.

Typically, this type of task is considered from the point of view of gas pollution, but in the new formulation, more extended, the wind regime (microclimate) in the area of worker's location will be taken into account Fig. 1. It is known, the speed of air flow in the working area should not exceed 0,2 m/s, with more there is discomfort.

Fig. 1. Examples of «temporary building» for trade near the motorway):
1 – active motor transport; *2* – barrier (fence);
3 – the location of the goods; *4* – the person (the seller);
5 – the location of the person's head, *6* – temporary building

There are three variants of the place of trade in the range of vehicles (Fig. 2 – 4): the first option – the seller carries out the trade of the products without the presence of a «temporary building»; the second option – the seller carries out trade of the products near the «temporary building» which does not have a subassembly; the third option – the seller carries out trade of the products near the «temporary building» which has a subcategory.

As a result of the calculations, a field of velocity and concentration of the pollutant in the investigated area was obtained. Fig. 5 shows the change in the air flow rate at the level of the head of the employee (locally), depending on the variant of the trade place. In the first variant $u = 3{,}5$ m/s, in the second $u = 1{,}6$ m/s, in the third $u = 0{,}26$ m/s, the presence of "temporary building" reduces the rate by twice, and the presence of an eaver in the same structure reduces the speed by 5 times, in relation to the situation when the eaver is absent. From the point of aerodynamics, the presence of an eaver leads to the vortex from its sharp edge, to ensure the finiteness of speed in accordance with the Chaplygin-Zhukovsky postulate, the formation of the vortex of a specific power provides a reduction in speed in the area of the head of the employee.

Fig. 6 shows the change in the concentration of the pollutant at the level of the head of employee (locally), depending on the location of the place of trade. In the first variant $C = 0{,}53$ mg/m^3, in the second $C = 0{,}35$ mg/m^3, in the third $C = 0{,}21$ mg/m^3, the presence of "temporary building" reduces the concentration by 1,5 times, and the presence of an eaver in the same structure reduces the concentration by 1,75 times relative to the situation when there is no eaver.

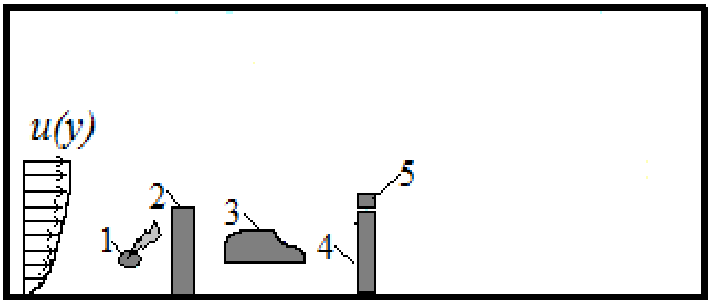

Fig. 2. Scheme of employee location in the trade zone near the highway (option 1):
1 – active motor transport; *2* – barrier (fence);
3 – the location of the goods; *4* – the person (the seller);
5 – the location of the person's head

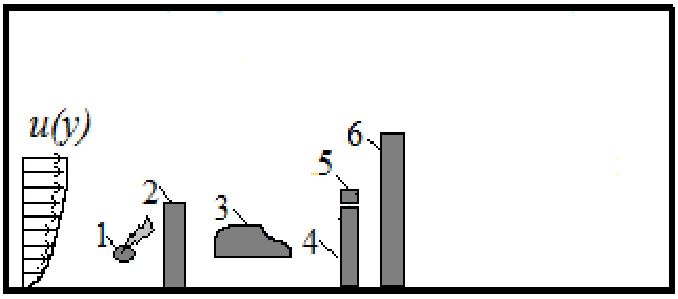

Fig. 3. Scheme of employee location in the trade zone near the highway (option 2):
1 – active motor transport; *2* – barrier (fence);
3 – the location of the goods; *4* – the person (the seller);
5 – the location of the person's head;
6 – temporary building without an eaves

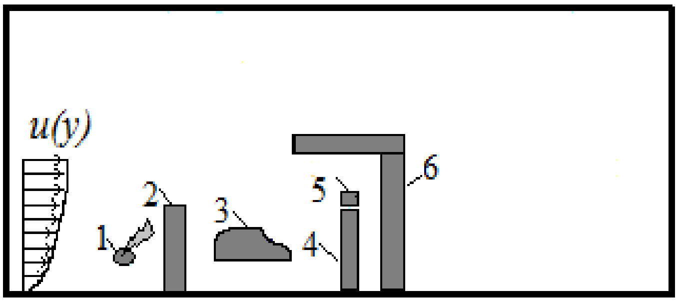

Fig. 4. Scheme of employee location in the trade zone near the highway (option 3):
1 – active motor transport; *2* – barrier (fence);
3 – the location of the goods; *4* – the person (the seller);
5 – the location of the person's head;
6 – temporary building with an eaves

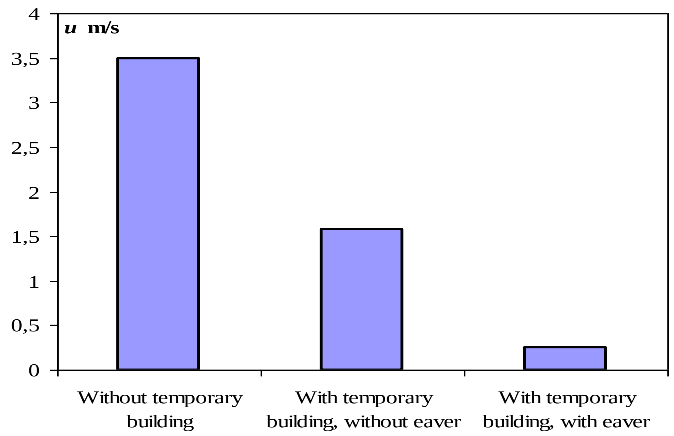

Fig. 5. Change of air flow rate at the level of the head of employee

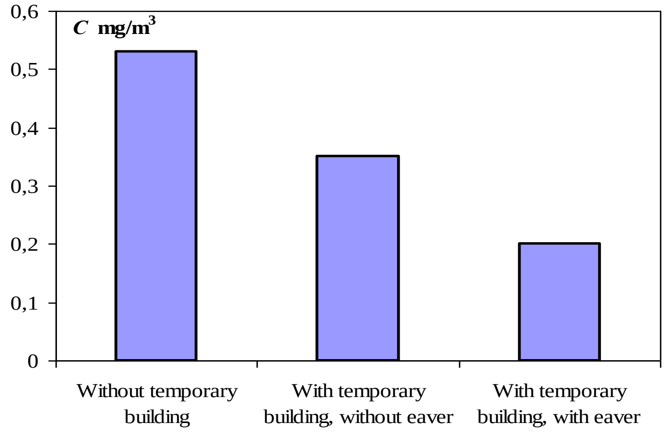

Fig. 6. Change of pollutant concentration at the level of the head of employee

It is note worthy that eaver affects the change in the concentration of the pollutant, but plays a more significant role in reducing the air flow velocity, providing comfortable microclimate conditions in the working area. Prolonged or systematic stay in such a work area does not affect the condition of people, provides high ability to work and comfort.

Conclusions. The mathematical model for forecasting microclimate parameters was developed, simulation of the place of trade, located within or outside the location of «temporary building». The numerical algorithm of the finite-difference method for solving the hydrodynamic problem on the basis of the Navier–Stokesequation and the mass transfer problem is used. The created software allows to carry out computational experiments for the study of the field of air flow velocity and the distribution of the concentration of the pollutant in the microzone of the place of trade. The regularities of changing air velocity at the level of the head of the worker are determined, depending on the presence of a «temporary building» with or without an eaver. Reducing the air flow rate to 0,26 m/s due to changes in aerodynamics provides comfortable working conditions for employee's work.

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УДАР КРУГЛОГО ТЕЛА О ПОВЕРХНОСТЬ ИДЕАЛЬНОЙ НЕСЖИМАЕМОЙ ЖИДКОСТИ

В работе рассматривается задача в плоской постановке об ударе круглого тела о поверхность идеальной несжимаемой жидкости, не имеющей границ. Тело частично погружено в жидкость, а его погруженная часть имеет форму кругового сегмента. В некоторый момент времени происходит удар, после чего тело мгновенно получает поступательную скорость и вращательную скорость вокруг оси, перпендикулярной плоскости, в которой рассматривается течение. С помощью конформного отображения, переводящего область полуплоскости с вырезанным сегментом в полуплоскость, данная задача сводится к смешанной задаче Келдыша–Седова для верхней полуплоскости, решение которой известно в квадратурах. Таким образом, была решена ударная краевая задача со смешанными граничными условиями. Был найден комплексный потенциал жидкости в мгновение после удара, а также потенциал скорости жидкости на участке соприкосновения тела с жидкостью. Полученные результаты проанализированы в случаях влияния на жидкость со стороны тела только одной компоненты скорости, либо всех трех компонент. Результаты были проиллюстрированы для различных углов погруженного сегмента и проведено сравнение с результатами для плавающей пластинки.