DOI: 10.46299/ISG.2024.MONO.TECH.4.10.1

## 10.1 Prediction of microclimate parameters in working areas when using a humidifier

**The totality of parameters that influence the microclimate in work areas and the health of workers.** The microclimate of industrial premises is determined by a set of parameters that affect the heat exchange of the human body (Fig. 1).

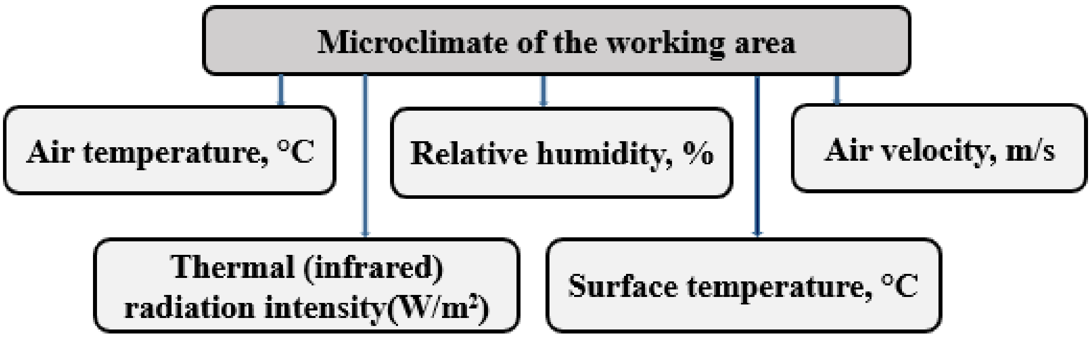


**Figure 1.** Indicators affecting the microclimate in working areas

Each of the parameters. both separately and in combination with others, affects the physiological functioning of the employee's body, namely the thermoregulation of the body, which determines his well-being and working capacity. When changing external environmental conditions, thermoregulation in the human body occurs due to the strengthening or weakening of physiological processes that cause heat generation in the body and also affect the heat transfer from the human body to the environment. The human body is able to maintain a quasi-stable body temperature with fairly wide fluctuations in environmental parameters.

Heat exchange between a person and the environment $Q$ is carried out due to thermal processes occurring between a person and the environment. as well as inside the human body (Fig. 2).

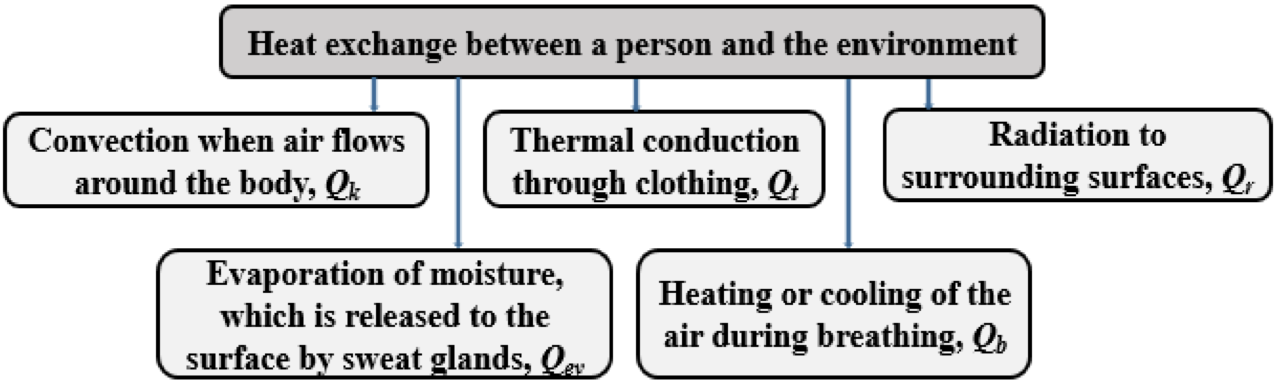


**Figure 2.** Heat exchange between a person and the environment

Although the human body maintains a temperature of about 36.6°C with air temperature fluctuations from -40°C to +40°C. the temperature of some areas of the skin and internal organs can vary from 24°C to 37.1°C.

$$Q = Q_k + Q_t + Q_r + Q_{ev} + Q_b \, . \tag{1}$$

where $Q_k$ – heat transfer due to convection when air flows around a body; $Q_t$ – heat transfer by thermal conduction through clothing; $Q_r$ – heat transfer due to radiation to surrounding surfaces; $Q_{ev}$ – heat exchange due to the evaporation of moisture, which is brought to the surface by sweat glands; $Q_b$ – heat exchange due to heating or cooling of air during breathing.

A decrease in the temperature of the air environment leads to an increase in heat transfer by convection and radiation and can cause hypothermia of the body. When the air temperature increases, the opposite situation occurs. At an air temperature of more than 30°C, a person's working capacity begins to fall and heat transfer is practically carried out by sweating and evaporation of moisture. Prolonged exposure to high temperatures in combination with significant humidity leads to the accumulation of heat in the body and to hyperthermia – a condition when the body temperature rises to 38°C–40°C. With hyperthermia, or heat stroke, the symptoms include a headache, dizziness, general weakness, distortion of color perception, dry mouth, nausea, vomiting, sweating. The pulse and respiratory rate accelerate, the content of nitrogen and lactic acid in the blood increases. Pallor, bluish skin, dilated pupils, sometimes convulsions, loss of consciousness are observed (Fig. 3).

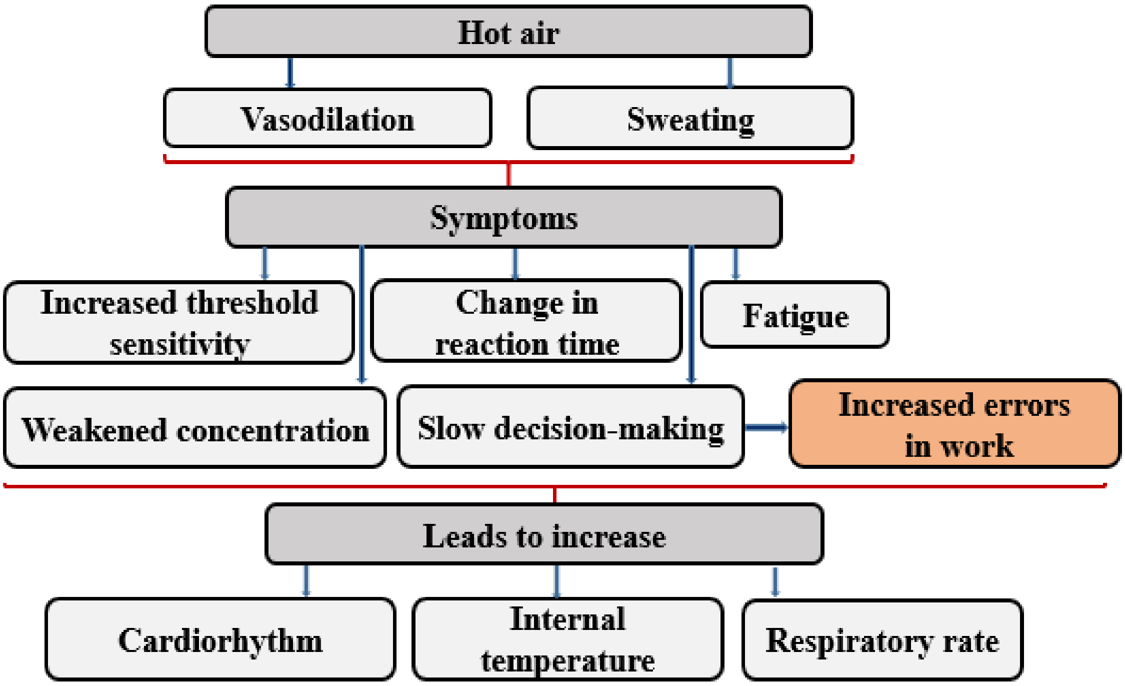


**Figure 3.** The effect of high temperature on a human condition

At low temperatures, significant air movement and humidity, the body overcools, which is called hypothermia. At the initial stage of exposure to moderate cold, there is a decrease in the respiratory rate and an increase in the volume of inspiration. With prolonged exposure to cold, breathing becomes irregular, the frequency and volume of inspiration increase, and carbohydrate metabolism changes (Fig. 4).

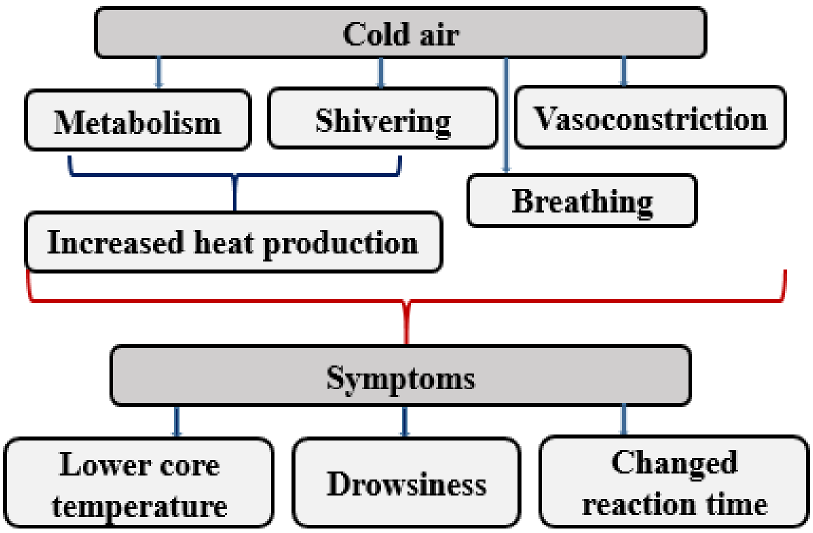


**Figure 4.** The effect of low temperature on a human condition

Muscle tremors appear, as external work is not performed and all the energy of the tremor is converted into heat. This allows for some time to delay the decrease in the temperature of the internal organs. The consequence of the action of low temperatures is cold injuries.

Air humidity has a significant impact on the thermoregulation of the human body. An increase in relative humidity to 85% complicates thermoregulation, and a decrease to 20% causes discomfort associated with drying out of the mucous membranes and skin. The optimal value of relative humidity is 40–60%.

Air velocity is also an important factor affecting human well-being. In the warm season. moderate air movement promotes heat exchange in the human body and improves its well-being; in the cold season and at low air temperatures, it contributes to hypothermia of the body as a whole and its individual parts, which can lead to frostbite and the occurrence of colds. The minimum air velocity felt by a person is 0.2m/s.

**Normalization of microclimate parameters.** Sanitary and hygienic standardization of the microclimate is carried out in accordance with state sanitary standards, which establish optimal microclimatic conditions and permissible microclimate parameters at workplaces in industrial premises. When setting standards, the total energy expenditure of the body when performing work is taken into account, which depends on the category of work in terms of its difficulty, as well as the time of year. There is a cold period of the year, which is characterized by an average daily outdoor temperature of +10°C and below, and a warm period with a temperature above +10°C. Optimal meteorological conditions apply to the entire working area, and permissible ones are established separately for permanent and non-permanent workplaces. In industrial premises located in areas with an average maximum temperature of the hottest month above 25°C, an increase in the upper limit of the permissible temperature is allowed. but not more than 3°C. In this case, the air speed should be increased by 1.1 m/s. and the relative humidity should be reduced by 5% for each degree exceeding the permissible air temperature limit.

In production premises where it is impossible to establish permissible microclimate values due to technological requirements for the production process, technical inaccessibility or economically justified inexpediency, measures are provided to protect against possible overheating or hypothermia, as well as measures to increase or decrease air humidity.

**Justification of the need for humidification of air in work areas.** A healthy atmosphere with an optimal level of humidity is one of the main factors for increasing employee productivity. A comfortable humidity level of 40-60% can be ideal for people to concentrate and feel good. At values below 50%, the mucous membrane begins to dry out, which increases susceptibility to respiratory diseases.

Humidified air binds dust particles much faster than dry air. Reduced dust levels and improved air circulation have a positive effect on breathing problems in allergy or asthma sufferers.

In rooms that require cooling or heating depending on the season, there is a problem with the level of relative humidity and its impact on workers, which requires temperature control. Adiabatic humidification systems provide a sustainable, environmentally friendly solution. If the room requires high heat loads from outside or inside, aerosol droplets in the air extract heat energy and provide energy-efficient cooling. If the relative humidity decreases during an increase in heat load, moisture comes into the air through the same system.

There are main advantages of humidifying air in workplaces:

- reduction in the number of sick leaves due to a healthier indoor atmosphere;
- increasing productivity and improving employee well-being;
- reduction of dust pollution;
- protection against electrostatic discharge;
- high energy efficiency.

Dry air consists of 78% nitrogen. 21% oxygen, and about 1% carbon dioxide. inert and other gases. If there is water vapor in the air, then such air is called humid air. Dry atmospheric air is characterized by the constancy of its composition and can be considered as a homogeneous gas. The state of a homogeneous gas is usually determined by two parameters, namely pressure and temperature, and at constant pressure – only by temperature.

The content of water vapor in the air is not constant. The main parameters of humid air include its temperature, degree of saturation. moisture content,heat content, density and specific volume. Maximum humidity (dew point) is characterized by the maximum amount of moisture that can be in the air at a certain temperature. Absolute humidity is characterized by the actual amount of moisture that is in the air at a certain temperature. Relative humidity is the ratio of absolute humidity to maximum humidity under given temperature conditions. Relative humidity is considered as a normative indicator when assessing working conditions.

Sources of excess moisture release can be production facilities in which water evaporates (all kinds of bathtubs, washing machines, etc.). Particularly intensive moisture release occurs when water is heated or mechanically stirred. Another source of moisture release is the worker's body. As noted above, the optimal relative humidity is 40–60%, and the amount of moisture released depends on the nature of the work performed and the temperature. In air excessively saturated with water vapor, the evaporation of moisture from the surface of the skin and lungs slows down, which can sharply worsen the health of the worker and reduce his working capacity. As in pure form. steam in the air can be superheated (unsaturated) and saturated.

Considering a typical office, the temperature deviation during the day is 1–2 °C, and the relative humidity is 5%. The necessary air exchange (in accordance with sanitary and hygienic requirements) is carried out by periodic ventilation. Employees most often complain of dry nose and difficulty swallowing, the incidence of workers increases. especially during the heating period. These consequences of poor health are due to the fact that in a heated room, the relative humidity ranges from 10% to 30%, in the evening and morning this indicator decreases even more due to the low outside temperature. Inhaling air with such low relative humidity by a person causes unpleasant dryness of the mucous membranes of the respiratory tract. Health deteriorates if work is associated with constant or frequent conversations. The first alarms, namely, dryness around the nasopharynx, sometimes with painful irritation, are most often not taken seriously. At low relative humidity, the function of the ciliated epithelium is disrupted: mucus thickens and cannot drain, lingering on the mucous membrane. In addition, the respiratory tract and lungs can remain healthy only if there is a sufficient amount of mucus and its timely removal. Due to this, all pathogenic microorganisms, as well as dust and other dirt remain in the respiratory tract and, under certain conditions, are able to penetrate the mucous membranes of the respiratory tract. As a result of working in such premises, the following diseases occur: inflammation of the paranasal sinuses, inflammation of the respiratory tract, inflammation of the pulmonary alveoli, lung infections [509].

In industrialized countries, respiratory diseases are second only to cardiovascular diseases. Almost 90% of the population suffers from colds at least once a year. A bacterial infection that is not recognized in time causes a deterioration in health for a significant period. If it is possible to maintain a relative humidity of 40–60%, depending on the temperature and working conditions in the room, there is a simultaneous decrease in the number of microbes in the air. Studies have shown that pneumococci die in less than 10 minutes at a humidity of 50%, and at 20% or 80% they can survive for more than two hours. Therefore, the greatest attention should be paid to humidification processes in the winter (heating) period, even at high relative humidity. Because when entering the room, the air does not change its absolute humidity, unlike the relative humidity,which decreases sharply [509].

The studies cited by the authors in the article [510] show that it is temperature, humidity, and indoor air quality that play a dominant role in improving the health and productivity of employees.

The relationship between seasonal variations and viral disease outbreaks has been the subject of much debate. Low temperatures are thought to increase the half-life of the virus, and low relative humidity is thought to negatively affect the processes that lead to viral inactivation. As a result, there is growing interest in how indoor temperature and relative humidity affect the risk of airborne virus transmission. Studies and observational data suggest that high temperatures, as well as relative humidity in the range of 40–60%, may reduce transmission of the novel coronavirus (COVID-19) [511].

Since people spend a significant amount of time indoors, the quality of the indoor environment affects the cognitive functions of those who are there. and accordingly, their learning. work and productivity. The article [512] studies the influence of indoor air quality, the level of heat load, lighting, noise on attention,perception, memory, and language functions. However, the influence of a particular factor is determined by its compliance with regulatory indicators. Therefore, the influence of these factors on different cognitive functions is quite different.

To investigate the interaction between the cool mist humidification process and the floor heating process, experimental studies were conducted in rooms with temperatures of 21°C, 23°C, 25°C and with set values of relative humidity of 45%, 55%, 65% in the article [513]. The problem of floor overheating must be taken into account when humidifying air at temperatures of 25°C and above. The humidification process makes the air temperature distribution more uniform, but significantly increases energy consumption. The set relative humidity of 45% meets health safety requirements with minimal energy consumption. A relative humidity of 55% can be selected at temperatures below 25°C for better thermal comfort in individual situations where energy consumption is acceptable.

In the article [514], studies were conducted to determine the effectiveness of using humidifiers that increase indoor air humidity to reduce or prevent symptoms of dry eyes, skin, and upper respiratory tract infections at work and in educational institutions.

**Justification of the need for humidification of air in residential premises.** Humidity in residential premises directly affects a person's physical and emotional well-being, as well as their general health. Even minor deviations from the established norm can lead to a number of unpleasant diseases.

To create a healthy and comfortable microclimate in an apartment or house, it is important to first determine the humidity level in the rooms and, if necessary, promptly take measures to normalize it.

For a person to feel good. the humidity in living spaces should be between 30% and 45%. However. these figures can vary to a greater or lesser extent, depending on the purpose of the room.

Optimal parameters of living spaces:

- for a children’s room – from 45% to 60%;
- for the library and office – from 30% to 40%;
- for the bedroom – from 40% to 50%;
- for the kitchen, bathroom, living room – from 45% to 60%.

It is quite difficult to independently maintain the required air humidity levels, as they strongly depend on external factors: the season, weather conditions, degree of heating, intensity of household chores, number of people in the room,number of indoor plants, etc.

Therefore, to maintain optimal living conditions indoors, household dehumidifiers are installed in a house or apartment. If there is not enough liquid in the air, special humidifiers are used; the devices operate in automatic mode, continuously maintaining humidity within normal limits.

The main physical factors that affect the safety of workers include: temperature, humidity, air velocity. The task of assessing the levels of harmful factors in working areas at industrial enterprises is urgent.

One of the important tasks is to develop a comprehensive methodology that allows predicting the wind regime, humidity and temperature in working areas in the presence of the use of an artificial air humidifier, taking into account the droplet evaporation process.

To implement the task, there are various methods.

**Methods of modeling and evaluation of air environment parameters in working areas.** To solve such practical problems as assessing the comfort of the microclimate or determining the required power of the system providing the microclimate, it is necessary to determine the distribution of microclimate parameters in the working area and their change over time. In this case, modeling of processes is used or their reproduction by methods that adequately reflect the conditions of the processes in reality.

The main goals of mathematical modeling are:

– research, for in-depth study of the processes of formation or development of new technologies for ensuring optimal microclimate conditions;

– calculation, for determining the parameters of the installation of a system for ensuring optimal microclimate conditions in design conditions and the operating mode of the system in operational conditions.

Three types of modeling are usually used to simulate the processes of microclimate formation:

– mathematical modeling based on solving a system of equations in differential or algebraic form, describing the air, moisture and gas regime of the working area;

– physical modeling in natural conditions or on models geometrically similar to a natural object, to which physical processes are transferred using scale relationships;

– analog modeling – a type of physical, when real processes are replaced by others that have a formally similar mathematical description.

Mathematical modeling represents physical processes in a simplified idealized form. The reality and reliability of physical processes is ensured by physical modeling.

Physical modeling is carried out in natural conditions and on geometrically similar models. Physical modeling is performed using trays, channels, wind tunnels and other experimental installations (Fig. 5). However, there are a number of difficulties that complicate the unambiguous transfer of the results of physical modeling to real objects:

– correspondence of scales;

– agreement of criterion numbers (for example, Re, Fr);

– preservation of the integrity of the studied samples, etc.

Full-scale studies are carried out on operating objects. One-time surveys and long-term observations (monitoring) of the object are possible.

However, in natural conditions it is difficult to establish the regularities of certain processes due to the large number of random obstacles. In this case, it is important to ensure long-term observation and study of the object (using modern measuring and computing devices).

In addition to expensive natural surveys, it is possible to conduct research in laboratory conditions on models similar to the natural object. The laboratory-model method has a number of advantages and disadvantages.

Advantages:

– ability to study objects that have not yet been created in nature;

– ability to systematically study the influence of any factor from the entire set of factors;

– ability to study rapidly changing phenomena;

Disadvantages:

– results of modeling can only be systematically extended to similar phenomena;

– significant time spent on making models and conducting experiments;

– large material costs for expensive equipment and laboratory equipment.

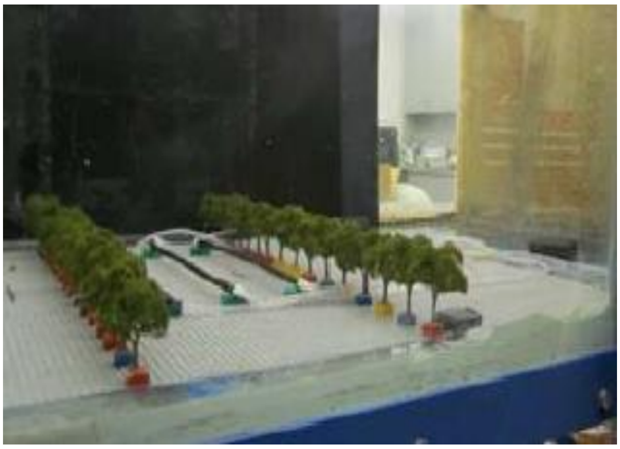

**Figure 5.** Experimental studies [515-516]

Mathematical modeling is based on solving the system of equations of motion, heat and mass balance of gas impurities in differential form in partial derivatives. The system of equations is supplemented by boundary conditions, which include boundary and initial conditions. The solution of the system allows you to determine the distribution of microclimate parameters and their change in time. These include: analytical models and numerical models.

Simple analytical deterministic models are based on empirical data and balance relations for a given air environment. With the help of such models, you can obtain approximate estimates of the main indicators of the state of the environment for large territories (city, region, etc.). Statistical models are built based on air (water) pollution observation data and monitoring data with subsequent analysis of time series. Such models are unsuitable for long-term forecasts, but are convenient to use, since they have a low development cost, and they are also used mainly for processing monitoring data. During operational forecasts in the environment, especially in the absence of detailed information about the structure of flows and the composition of substances, it is advisable to use models based on analytical solutions of partial differential equations. Most of such solutions were obtained for simple flow schemes in the case of constant or specially specified environmental parameters.

Despite the above limitations, analytical models, due to their relatively simple implementation, are indispensable in the analysis of the basic laws of the process under study.

Analytical methods include: the Gaussian and Lagrange methods, and their modifications. The Gaussian analytical method and its modifications solve simplified equations of impurity transport taking into account a point constant emission source and a point instantaneous emission source. These methods do not take into account the change in the wind speed profile with height, the dispersion coefficients are determined empirically, but not for all regions.

The Lagrange analytical method and its various modifications study the movement of particles according to their trajectories; they are used for large-scale transports, namely "ARCO", "MOE", "NAME", "QWIC".

In the process of solving practical problems in the field of environmental protection and labor protection, numerical algorithms for solving partial differential equations have become the most widely used. As a rule, they are based on finite difference or finite element methods. These algorithms allow taking into account in detail the complex structure of flows and the shape of the boundaries of the area, relief features, etc. At the same time, they require the development of special software, justification of the accuracy of convergence.

Numerical methods are the most effective tool for solving forecasting problems related to pollution of working areas in open areas. Among them are: URB – 3D Wind Model, CFD (CWE) – Computational Fluid Dynamics Model. These models allow you to quickly calculate the state of the air environment parameters in working areas and in the surrounding area, taking into account the main physical factors affecting them.

CFD models are primarily designed to simulate wind flow around objects. In the context of microscale air quality, these objects usually consist of buildings, trees, cars, screens, etc (Fig. 6).

There are three main steps in CFD air quality simulation: creating a two-dimensional or three-dimensional geometry; modeling wind flow; modeling the dynamics of changes in the factor variable). CFD models are characterized by a high level of detail: the step in the planar or spatial coordinate is about 1 m or even less. The modeled area is usually limited to a region up to 1 km long.

It should be emphasized that abroad, the Navier-Stokes equations are used for CWE wind flow modeling problems - one of the fundamental models of aerodynamics. Numerical models make it possible to reproduce the process of air pollution close to a physical experiment.

Numerical models have the following advantages:

– high accuracy of calculations;

– taking into account turbulence conditions;

– taking into account the underlying surface;

– taking into account the unevenness of the velocity field.

Numerical models have the disadvantages:

– high cost of the license package;

– requires highly qualified workers;

– inability to take into account all boundary conditions.

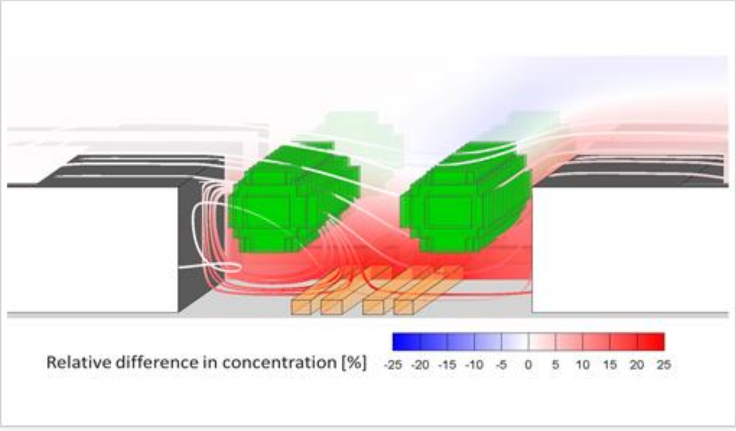


**Figure 6.** CFD modeling [516]

Therefore, from a practical point of view, it is very important to develop calculation methods that meet the requirements:

– ease of practical application;

– small base of initial data;

– speed of calculation;

– ease of processing and interpretation of quantitative results.

**The influence of the main indicators of the microclimate of the working area air on workers in various industries.** The health of the working population is influenced not only by the biological properties of the organism, but also by social factors that are formed under the influence of the working conditions of this production, economic conditions, the way and quality of life of workers.

According to statistics, in Ukraine, every fourth worker works in conditions that do not meet sanitary and hygienic standards in terms of dust content, chemical impurities in the air of the working area, vibration, noise, infra- and ultrasound, ionizing and non-ionizing radiation, difficulty and intensity of work. The most dangerous are working conditions in the coal industry – 74.1% and in metallurgy – 59.6%.

At enterprises, the well-being and health of workers depends on the microclimate of production premises. The main indicators of the microclimate of the working area air include: *temperature, relative humidity, air velocity*. The parameters of the microclimate and the state of the human body are also affected by the intensity of thermal radiation of various heated surfaces, the temperature of which may exceed the temperature in the production room.

The production microclimate is variable, has an uneven distribution horizontally and vertically. The values of temperature, humidity, air velocity, radiation intensity depend on the characteristics of production technologies, climatic conditions of the area, building structures, and the organization of air exchange with the external environment.

One of the most developed industries in Ukraine, which accounts for more than a quarter of all industrial production, is *ferrous metallurgy*. In metallurgical production, the replacement of old technological equipment and the introduction of new technologies is extremely slow. This leads to a significant impact of harmful factors of the production environment of metallurgical enterprises on the health of workers, which leads to an increase in occupational health risks. Working conditions in modern metallurgical plants are determined by both technological processes and the features of the equipment of the workshops of these enterprises. With an increase in the volume of steelmaking furnaces, the volume of hot sinter, heated metal structures, and powerful heat sources, the heat input into the premises of the workshops also increases. For premises with excess heat, a *high air temperature* exceeding the maximum permissible levels and *low relative humidity* in the warm season are characteristic. The *level of humidity is also affected by the dustiness* of the air in metallurgical workshops, which occurs at different stages of the technological process [517]. Overheating can be a consequence of the influence of high temperature of the production environment in “hot” workshops, such as blast furnaces, open-hearth furnaces, and rolling mills. About 30-40% of the heat required by the production technology enters the air of the production premises. This problem is especially relevant in the summer, when the air temperature in the working area can reach 30-40°C and more. Some short-term labor operations are performed at air temperatures of 60-90°C and above. Overheating of the body is considered a state of thermal balance disturbance with increased heat production and difficulty in its dissipation, which is accompanied by an increase in the amount of thermal energy in the body.

In the hot season, due to intense solar radiation and high ambient temperature, the air in closed production spaces with metal frames (railway cars, locomotives, car interiors, tractors, combines) heats up especially quickly. In this case, the outer metal shell can heat up to 45–55°C.

High temperature, as a degree of air heating, is observed: *in foundries, thermal, blacksmith shops, in a number of textile, rubber, food, chemical, agricultural industries, production of cement, slate, glass, brick and other building materials* and is most often caused by the operation of the main technological equipment.

Overheating is exacerbated by heavy physical labor, high humidity, and still air.

Workers' well-being deteriorates when working in tight or water vapor-impermeable clothing. The danger of overheating of the body occurs when exposed to high temperatures and thermal radiation, especially in the presence of factors that hinder heat exchange with the external environment. The complicated process of heat exchange, namely the transfer of heat from the body to the environment, is characterized by the accumulation of heat in the human body. This is accompanied by the tension of the mechanisms of physical thermoregulation: the expansion of blood vessels of the skin, the acceleration of blood flow through the vessels and increased sweating.

When the air temperature rises to 33°C, heat transfer by conduction and radiation becomes ineffective, it occurs only by evaporation, and with increased air humidity this path of heat transfer also becomes difficult. Under such circumstances, the balance between the formation of heat in the body and its transfer to the external environment is disturbed, which causes heat retention and overheating. The period of overheating, characterized by the preservation of normal body temperature, is called *the compensation stage*. Overexertion of thermoregulation leads to its exhaustion, and an increase in body temperature indicates the onset of the second period of overheating - *the decompensation stage*. An increase in body temperature is accompanied by a sharp disruption of the central nervous system, respiratory and circulatory systems, and increased metabolism. A further increase in body temperature and overexertion of the nerve centers can cause their exhaustion with significant disorders of the respiratory and cardiovascular systems and a decrease in blood pressure. Hypoxia develops. Profuse sweating also has negative consequences – *dehydration, impaired electrolyte metabolism with the loss of cations, anions, and some organic substances important for the body*. *Thickening of the blood and an increase in its viscosity* create an additional burden on the circulatory system and contribute to the development of heart failure. Acute diseases can occur as a result of overheating – *hyperthermia, convulsions, and heat stroke*. Prolonged exposure to high temperatures leads to *chronic overheating*.

Overheating of workers during the performance of their labor duties is especially dangerous. After all, due to the need to comply with regulated technological processes and regimes, the employee cannot always respond in time to the first signs of overheating. In addition, in hot weather, the negative impact on the employee of other harmful production factors increases, especially when working in confined spaces, with reduced air movement and increased humidity.

Low temperature is characteristic of work performed outdoors: *logging, construction, road, peat work*. *As well as work in unheated rooms in the cold season, when servicing artificially cooled rooms, in particular, cold storage rooms, in warehouses, in the shipbuilding industry, in elevators*.

High levels of air humidity are characteristic of *pickling, galvanic, fish processing, dyeing shops, leather, paper, construction and other industries*. Technological processes associated with increased humidity take place at *food industry enterprises, namely at dairy and meat processing plants, at leather processing plants, in galvanic and pickling departments in mechanical engineering, in spinning and weaving workshops*, increased humidity is often created artificially, in order to implement the tasks of the technological process.

Air mobility is created as a result of temperature differences in adjacent areas of the room, the penetration of cold air flows from the outside into the room, during the operation of ventilation systems, etc. Increased air velocity is observed during the operation of special air conditioning and ventilation units [517].

Microclimate parameters, such as temperature, relative humidity, air velocity, and the level of thermal radiation, are important factors of the production environment, on which working conditions, and therefore the health of workers, depend to a large extent. Therefore, the organization of work with optimal parameters of the microclimate of the production environment remains not only one of the main tasks, but also a labor problem.

The results of the research indicate that in production conditions all microclimate parameters affect a person simultaneously. Therefore, it is important to identify their total impact on the worker. To measure microclimate parameters, various devices are used that allow conducting research locally, at a specific point in space. One of the ways to predict and assess the field of temperature, humidity, and air velocity in working areas is to develop a mathematical method based on the equations of transport and evaporation of a droplet. The solution of these equations is based on the numerical method of finite differences. Software based on the developed method allows conducting a large number of computational experiments for preliminary assessment of microclimate parameters in working areas in open areas.

**Prediction of microclimate parameters in working areas in an open area when using a humidifier.** Air humidity is one of the components of ensuring a comfortable microclimate. All humidifiers are divided into household and industrial. At the same time, if domestic ones are necessary to maintain comfortable conditions for human well-being, then the use of industrial humidifiers significantly affects the technological process and the quality of finished products. Figure 5 shows the use of humidifiers for the comfortable stay of trade workers in open areas and consumers [518].


**Figure 7.** Application of humidifiers in working areas in the open area

Solving the problem of forecasting microclimate parameters in the working area when using a humidifier is divided into two main stages. At the first stage, the equations simulating the dispersion of water,water vapor, temperature change under the influence of wind and atmospheric diffusion (2–3) are solved [518].

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}=\mu\Delta C+\sum_{i=1}^{n}Q_i\delta(x-x_i)\delta(y-y_i)\,. \quad (2)$$

$$\frac{\partial W}{\partial t}+\frac{\partial uW}{\partial x}+\frac{\partial vW}{\partial y}=\mu\Delta W\,. \quad (3)$$

$$\frac{\partial T}{\partial t}+\frac{\partial uT}{\partial x}+\frac{\partial vT}{\partial y}=a\Delta T\,. \quad (4)$$

where $C$ – concentration of water droplets in the air; $u$, $v$ – components of the wind speed vector; $\mu=(\mu_x,\mu_y)$ – coefficient of turbulent diffusion; $x_i$, $y_i$ – coordinates of the source of water drops; $\delta(x-x_0)\,\delta(y-y_0)$ – the Dirac delta function, which simulates the entry of water droplets into the atmosphere. The values of the diffusion coefficients are calculated according to the formulas: $\mu_x=(0{,}1\div 1)\cdot U$ , $\mu_y=(0{,}1\div 1)\cdot U$ , where $U$ – wind speed, $W$ – concentration of water vapor in the air, $T$ – air temperature, $\sigma$ takes into account the rate of water evaporation, $a$ – coefficient of thermal conductivity [518].

The development of the method includes the solution of equations (2)–(4) using the finite-difference method, the numerical integration of equations (2)–(4) is performed on a rectangular difference grid using the difference analog and an implicit five-step difference splitting scheme [516, 518]. The application of this scheme is given for the equation (5)–(10).

The time derivative is approximated by the divided difference "backward":

$$\frac{\partial C}{\partial t}\approx\frac{C_{ij}^{n+1}-C_{ij}^{n}}{\Delta t}\,.$$

In convective derivatives. the components of unidirectional transfer are written as:

$$\frac{\partial uC}{\partial x}=\frac{\partial u^{+}C}{\partial x}+\frac{\partial u^{-}C}{\partial x};\ \frac{\partial vC}{\partial y}=\frac{\partial v^{+}C}{\partial y}+\frac{\partial v^{-}C}{\partial y}.$$

Taking into account the previous expression, the convective derivatives are approximated by separated differences "against the flow" in the upper time layer:

$$\frac{\partial u^{+}C}{\partial x}\approx\frac{u^{+}_{i+1,j}C^{n+1}_{i,j}-u^{+}_{i,j}C^{n+1}_{i-1,j}}{\Delta x}=L^{+}_{x}C^{n+1},$$

$$\frac{\partial u^{-}C}{\partial x}\approx\frac{u^{-}_{i+1,j}C^{n+1}_{i+1,j}-u^{-}_{i,j}C^{n+1}_{i,j}}{\Delta x}=L^{-}_{x}C^{n+1},$$

$$\frac{\partial v^{+}C}{\partial y}\approx\frac{v^{+}_{i,j+1}C^{n+1}_{i,j}-v^{+}_{i,l}C^{n+1}_{i,j-1}}{\Delta y}=L^{+}_{y}C^{n+1},$$

$$\frac{\partial v^{-}C}{\partial y}\approx\frac{v^{-}_{i,j+1}C^{n+1}_{i,j+1}-v^{-}_{i,j}C^{n+1}_{i,j}}{\Delta y}=L^{-}_{y}C^{n+1}.$$

The components of the speed *u* are determined on the vertical faces of the difference cells, and the components of the speed *v* are determined on the horizontal faces. The indexes of these faces correspond to the indexes of cells located to the right or above the corresponding boundary.

Second derivatives are approximated as follows:

$$\frac{\partial}{\partial x}(\mu_x\frac{\partial C}{\partial x})\approx\mu_x\frac{C^{n+1}_{i+1,j}-C^{n+1}_{i,j}}{\Delta\quad x^2}-\mu_x\frac{C^{n+1}_{i,j}-C^{n+1}_{i-1,j}}{\Delta\quad x^2}=M^{-}_{xx}C^{n+1}+M^{+}_{xx}C^{n+1};$$

$$\frac{\partial}{\partial y}(\mu_y\frac{\partial C}{\partial y})\approx\mu_y\frac{C^{n+1}_{i,j+1}-C^{n+1}_{i,j}}{\Delta\quad x^2}-\mu_y\frac{C^{n+1}_{i,j}-C^{n+1}_{i,j-1}}{\Delta\quad x^2}=M^{-}_{yy}C^{n+1}+M^{+}_{yy}C^{n+1}.$$

where $L^{+}_{x}$, $L^{-}_{x}$, $L^{+}_{y}$, $L^{-}_{y}$, $M^{+}_{xx}$, $M^{-}_{xx}$, $M^{+}_{yy}$, $M^{-}_{yy}$ – conventional signs of difference operators. Taking into account the above signs, the difference analog of the transfer equation (2) is written as follows:

$$\frac{C^{n+1}_{i,j}-C^{n}_{i,j}}{\Delta t}+L^{+}_{x}C^{n+1}+L^{-}_{x}C^{n+1}+L^{+}_{y}C^{n+1}+L^{-}_{y}C^{n+1}+\sigma C^{n+1}_{ij}=$$

$$= (M_{xx}^{+}C^{n+1} + M_{xx}^{-}C^{n+1} + M_{yy}^{+}C^{n+1} + M_{yy}^{-}CO^{n+1}) + q_{ij}\delta_{ij} . \qquad (5)$$

where $Q_i(t)$ – the intensity of the corresponding *i-th* source placed in the difference cell «*ij*», $\delta_{ij}$ – number «1» or «0», depending on whether the source of pollution is located in the difference cell *«ij»* or not, $q_{ij} = Q_i(t)/(\Delta x \Delta y)\ q_{ij}$ , $\Delta x \Delta y$ – the area of this cell.

The difference equation (5) is split into five difference equations so that at each step only one direction of disturbance transfer is taken into account, which is determined by the sign of the convective derivative. In this case. the differential equations take the following form:

– at the first step of splitting $k = \frac{1}{4}$,

$$\frac{C_{ij}^{n+k} - C_{ij}^{n}}{\Delta t} + \frac{1}{2}(L_x^{+}C^{k} + L_y^{+}C^{k}) =$$

$$= \frac{1}{4}(M_{xx}^{+}C^{k} + M_{xx}^{-}C^{n} + M_{yy}^{+}C^{k} + M_{yy}^{-}C^{n}); \qquad (6)$$

– at the second step of splitting $k = n + \frac{1}{2}.\ c = n + \frac{1}{4}$,

$$\frac{C_{ij}^{k} - C_{ij}^{c}}{\Delta t} + \frac{1}{2}(L_x^{-}C^{k} + L_y^{-}C^{k}) =$$

$$= \frac{1}{4}(M_{xx}^{-}C^{k} + M_{xx}^{+}C^{c} + M_{yy}^{-}C^{k} + M_{yy}^{+}C^{c}); \qquad (7)$$

– at the third step of splitting $k = n + \frac{3}{4}.\ c = n + \frac{1}{2}$,

$$\frac{C_{ij}^{k} - C_{ij}^{c}}{\Delta t} + \frac{1}{2}(L_x^{+}C^{k} + L_y^{-}C^{k}) =$$

$$= \frac{1}{4}(M_{xx}^{-}C^{c} + M_{xx}^{+}C^{k} + M_{yy}^{-}C^{k} + M_{yy}^{+}CO^{c}); \qquad (8)$$

– at the fourth step of splitting $k = n+1$. $c = n + \frac{3}{4}$,

$$\frac{C_{ij}^{k} - C_{ij}^{c}}{\Delta t} + \frac{1}{2}(L_x^- C^k + L_y^+ C^k) =$$

$$= \frac{1}{4}(M_{xx}^- C^k + M_{xx}^+ C^c + M_{yy}^- C^c + M_{yy}^+ C^k); \tag{9}$$

– at the fifth step of splitting. we take into account the source of contamination:

$$\frac{C_{ij}^{n+1} - C_{ij}^{n}}{\Delta t} = \sum_{i=1}^{n} \frac{Q_i(t^{n+1/2})\delta(x - x_i)\delta(y - y_i)}{\Delta x \Delta y}. \tag{10}$$

At the second stage of the calculation, the process of evaporation of water droplets is simulated. For this, equation (11) [518] is used:

$$\frac{\partial C}{\Delta t} = -\sigma \cdot (C - C_s), \tag{11}$$

where $C_s$ – the concentration of saturated vapor in a specific control volume at a specific air temperature in that volume.

The change in water concentration $C$ in each control volume is modeled by the first-order equation (12) [518]:

$$\frac{\partial C}{\partial t} = -\sigma \cdot C, \tag{12}$$

where $\sigma$ takes into account the rate of evaporation of water droplets. The analytical solution of this equation can be written in the form $C = C_0 \cdot e^{-\sigma t}$, where $C_0$ – the initial value of the water concentration in the control volume. Using this dependence, you can roughly estimate the value of the coefficient $\sigma$ based on the condition $e^{-10} \approx 0$, then $\sigma t = 10$, $t$ – the evaporation time. which is assumed to be equal $10^{-2}$ s for water drops $d = 1$ mkm, which corresponds to such a state of water as fog. From where we will get the approximate value of the coefficient $\sigma$.

At the second stage, the air temperature is recalculated in each difference cell due to the evaporation of water droplets. The following approach is used for express calculation of this process.

Let the heat that was used to evaporate water of elementary mass $dm$, is $Q_w = r \cdot dm$, $r = 2{,}3 \cdot 10^6$ J/kg. This heat will come from the environment, that is, from the air, the value of this heat is calculated as follows [518]:

$$Q_{air} = m_{cell} \cdot c \cdot T^n.$$

where $m_{cell}$ – mass of air in the cell, $c$ – specific heat capacity, $T^n$ – the current moment in time.

The evaporation process leads to a change in the amount of heat in the control volume of air [518]:

$$Q_{air} - Q_w = m_{cell} \cdot c_{air} \cdot T^n - r \cdot dm.$$

The mass and volume of air in the cell are [518]:

$$m_{cell} = \rho_{air} \cdot W_{cell},$$

$$W_{cell} = h_x \cdot h_y = 1.$$

As a result, the ambient temperature changes to $T^{n+1}$, and the amount of heat changes in the cell [518]:

$$m_{cell} \cdot c_{air} \cdot T^{n+1} = m_{cell} \cdot c_{air} \cdot T^n - r \cdot dm.$$

From the last ratio. the temperature at the new time step $n+1$ is calculated according to the formula [518]:

$$T^{n+1} = T^n - \frac{r \cdot dm}{m_{cell} \cdot c_{air}}. \qquad (13)$$

When calculating. the value of the dew point temperature is taken into account in each control volume, which is determined with the help of the device according to the values of the ambient temperature and humidity.

For simultaneous assessment of air temperature and humidity, it is advisable to use the effective air temperature, which is calculated according to the formula [518]:

$$T_{app} = -2.653 + 0{,}994 \cdot T_{air} + 0.0153 \cdot T_{dewpt}^2,$$

where $T_{app}$ – effective temperature, $T_{air}$ – air temperature, $T_{dewpt}$ – dew point temperature.

It is calculated based on information about relative humidity according to the formula [518]:

$$T_{dewpt} = \frac{b \cdot \gamma(T, RH)}{a - \gamma(T, RH)},$$

where $\gamma(T, RH)$ is calculated by the formula [518].

$$\gamma(T, RH) = \frac{a \cdot T}{b + T} + \ln(RH / 100),$$

where $T$ – air temperature, $RH$ – relative humidity, $a$, $b$ – constants, $a = 17.271$, $b = 237.7$. The large water cycle in nature is presented in the figure 8.

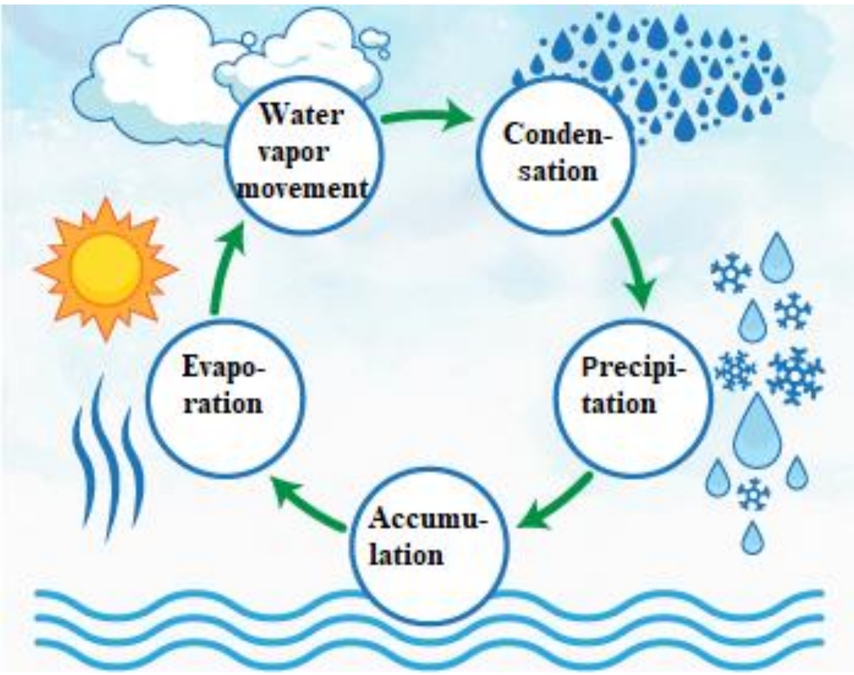


**Figure 8.** The large water cycle in nature

Schematization of the droplet evaporation process is presented in figure 9.

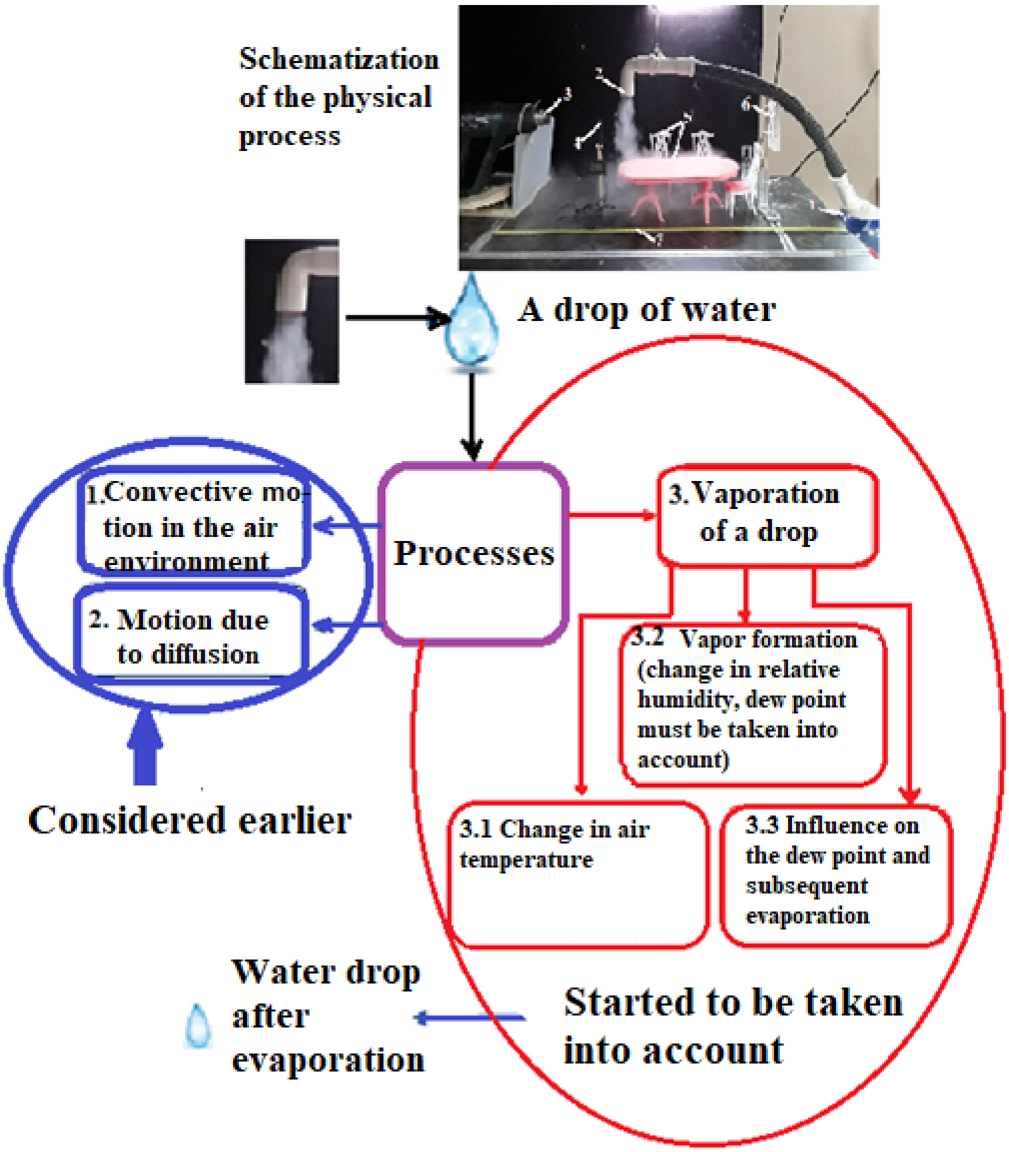


**Figure 9.** Schematization of the physical process in the calculation method of humidification

At the first stage of the research, an experiment was conducted to simulate the working area on the street (in an outdoor cafe). Furniture elements were presented on a scale of 1:10 (Fig. 10). modeling was carried out according to the Reynolds number. The supply of finely dispersed water was carried out at the top of the working area, as it happens in a cafe.

The experiment used a Supra HDS-104 ultrasonic air humidifier with volumetric flow rate $Q$=300 ml/h. Evaporation occurs due to high-frequency (ultrasonic) vibrations of a special membrane. which forcibly turns water into steam with the temperature of cold water. so this type of evaporation is often called "cold steam". The principle of action is that water from the tank is fed to a vibrating plate with a high (ultrasonic) frequency. where the water is broken into a finely dispersed water suspension. The air flow created by the fan supplies the water suspension, where it turns into a vapor state [518].

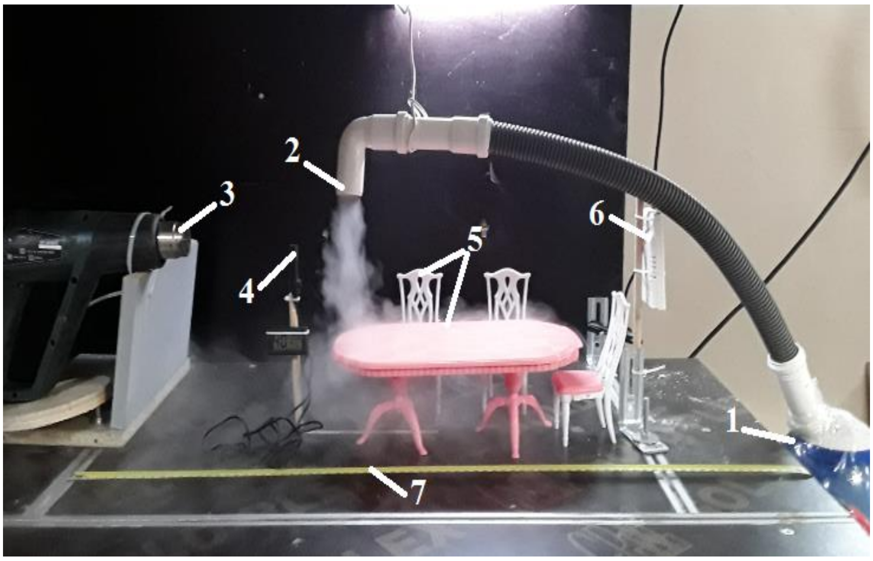


**Figure 10.** Scheme of the experimental installation: *V*=0 m/s, *Q*=0.832 ml/s:
1 – humidifier, 2 – steam supply nozzle, 3 – pressure fan, 4, 6 – devices for measuring humidity, 5 – furniture and working area.
7 – device for measuring distance (first script)

The vapor that is released looks very much like fog. The moisture obtained due to the operation of the membrane is captured by the air flow from the fan built into the humidifier and enters the air flow through a special spray nozzle. The atomizer is designed in such a way to deliver the aerosol as far as possible from the humidifier itself.

Figure 8 shows the experimental installation, which consisted of a Supra HDS-104 air humidifier with volume flow *Q*=300 ml/h, from which steam was supplied through an auxiliary nozzle at a height of *H*=25 cm from the surface of the installation. At the initial moment, the pressure fan does not work, steam is supplied through hole *d*=3 cm with constant consumption *Q*=0.832 ml/s. The Termo Hygrometer DC105 device was used to measure humidity. Humidity measurements were made at a height of 17 cm and at different distances from the emission source. The air flow was created by a channel fan Domovent 125 VKO 188 $m^3$/h, the speed of the air flow was measured using an anemometer – PM 6252B Digital Anemometer. The speed of the air flow was $V$=1.35 – 1.48 m/s, T=21°C. The length of the table $l = 0.29$ m was chosen as a characteristic size, the air viscosity was $\nu$=15.04·10$^{-6}$ m$^2$/s. the Reynolds number was used as a similarity criterion, which was equal to $\mathrm{Re} = \frac{V \cdot l}{\nu} = 0.3 \cdot 10^5$.

The work considered two scenarios of supplying the volumetric second flow rate of steam. In the first scenario – volumetric second consumption $Q$=0.832 ml/s, in the second scenario – volumetric second consumption $Q$=1.167 ml/s. Humidity measurements were carried out at different distances from the steam supply source. At the same time initial data were entered into the numerical calculation method: volumetric second consumption $Q$=1.167 ml/s, velocity of the incoming flow $V$=1.35 – 1.48 m/s and other parameters. The results of experimental measurements and calculated data obtained using the developed method are shown in table 1-2.

**Table 1.**

Humidity at different distances from the emission source $Q$=0.832 ml/s (first scenario)

| Distance, cm | Humidity, % (experiment) | Humidity, % (calculation by method) | Relative deviation of experimental data from numerical data, % |
|---|---|---|---|
| 5 | 91.5–93.5 | 90.2 | 1.3–3.7 |
| 10 | 82.7–87.3 | 81.7 | 1.2–6.9 |
| 15 | 76.4–79.2 | 75.9 | 0.7–4.3 |
| 20 | 63.6–67.5 | 62.8 | 1.3–7.5 |
| 25 | 51.2–57.4 | 50.6 | 1.2–9.5 |
| 30 | 44.5–46.1 | 43.3 | 2.8–6.5 |
| 35 | 40.5–43.3 | 40.1 | 0.9–7.9 |
| 40 | 38.4–39.7 | 37.5 | 2.4–5.9 |
| 45 | 34.5–36.1 | 34.1 | 1.2–5.8 |

From Table 1 it can be seen that the moisture values calculated by the developed numerical method are lower than those obtained in the experiment, which is due to the schematic viscosity. The relative deviation of the experimental data from the numerical ones on average varies in the range of 1.4% – 6.4%.

Figure 11 shows the formation of the fog field corresponding to the first scenario of the power of the vapor emission source $Q$=0.832 ml/s at air flow speed $V$=1.35 – 1.48 m/s. Finely dispersed water droplets are carried away by the air flow in the upper part of the working zone [518].

**Figure 11.** Fog field: $V$=1.35 – 1.48 m/s, $Q$=0.832 ml/s (first scenario)

If we compare Figure 10 and Figure 11, we can see that under the action of the wind flow, which moves at a speed of $V$=1.35 – 1.48 m/s, the humidity field shifts along the direction of the air flow, and due to diffusion processes, its humidity level decreases.

Next the results of research for the second scenario, when the power of the emission source is increased are given to Q=1.167 ml/s. Figure 12 – there is no air flow, that is $V = 0$ m/s. Figure 13 – air flow speed $V$=1.35 – 1.48 m/s.

Table 2 shows the results of numerical and experimental data with increased emission of the steam supply source $Q$=1.167 ml/s at an air flow velocity $V$=1.35 – 1.48 m/s.

Increasing the emission of the steam supply source in the second scenario of the experiment by 40% leads to an increase in humidity levels at different distances from the source on average from the range of 6.6% – 18.8%. This confirms that under the influence of diffusion processes in the air flow, a rapid dispersion of the humidity field occurs.

**Table 2.**

Humidity at different distances from the emission source *Q*=1.167 ml/s (second scenario)

| Distance, cm | Humidity, % (experiment) | Humidity, % (calculation by method) | Relative deviation of experimental data from numerical data, % |
|---|---|---|---|
| 5 | 97.4–99.3 | 96.1 | 1.4–3.3 |
| 10 | 88.6–93.4 | 87.9 | 0.8–6.3 |
| 15 | 82.5–85.7 | 82.3 | 0.2–4.1 |
| 20 | 69.6–73.8 | 68.5 | 1.6–7.7 |
| 25 | 57.2–63.4 | 57.1 | 0.2–9.7 |
| 30 | 50.5–52.1 | 50.3 | 0.4–3.6 |
| 35 | 46.5–49.4 | 45.9 | 1.3–7.6 |
| 40 | 44.4–45.9 | 43.7 | 1.6–5.1 |
| 45 | 40.6–42.5 | 40.5 | 0.2–4.9 |

Also from Table 2 it can be seen that the humidity values calculated by the developed numerical method are also lower than those obtained in the experiment, which is due to the scheme viscosity. The relative deviation of the experimental data from the numerical ones on average varies in the range of 0.9% – 5.8%.

Thus, the relative deviation of the experimental data from the numerical ones differs little for the two experimental scenarios, on average for both experiments it varies from 1% to 6%. This indicates the stability of the calculated numerical model, and minor differences are likely related to the experimental conditions, which cannot be reproduced unambiguously, since they depend on the parameters of the air environment.

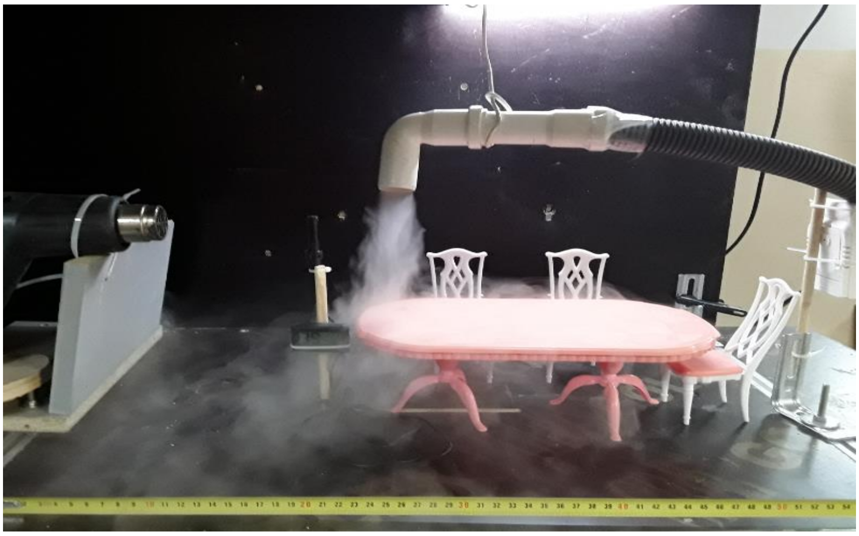

**Figure 12.** Fog field: *V* = 0 m/s, *Q*=1.167 ml/s (first scenario)

**Figure 13.** Fog field: *V*=1.35 – 1.48 m/s. *Q*=1.167 ml/s (second scenario)

Figure 14 shows the change in humidity at a height of 17 cm and at different distances from the emission source. Air humidity decreases with distance from the source of fog emission.

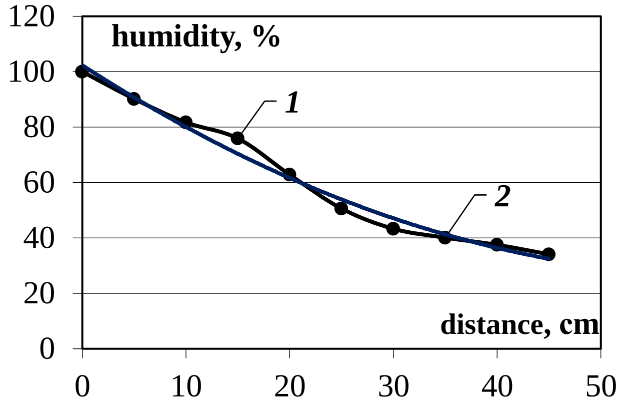


**Figure 14.** Changes in humidity at a distance from the emission source [518]: *1* – calculated dependence, *2* – trend line

The dynamics of changes in humidity levels with distance from the emission source can be described by a second-order polynomial dependence:

$$C(x) = a_2 \cdot x^2 + a_1 \cdot x + a_0 . \quad (14)$$

where *x* – відстань від джерела емісії вологи, $a_0$ =102.3, $a_1$= -2.4174, $a_2$= 0.0192. Достовірність апроксимації *R*=0.9863.

At the second stage of the research, a computational experiment was conducted based on the developed method. On the territory of the "Southern Machine-Building Plant" in the summer period, an open cafe for employees of the enterprise functions (Fig. 15, mark 2).

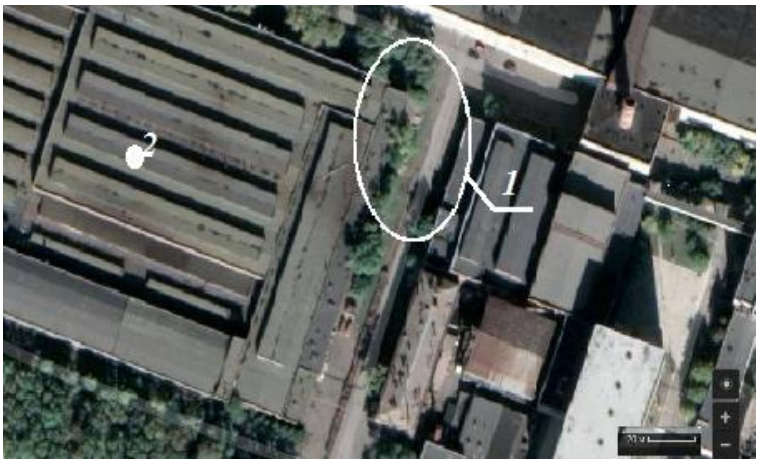


**Figure 15.** The territory of the rest area of the workers of the "Southern Machine-Building Plant" (Google Earth Image, 2024): *1* – summer cafe, *2* – foundry [518]

Next to the territory of the summer cafe is a foundry. The recreation area is designed for 12 people. The workshop employs welders, crane operators and metallurgists.

Figure 16 shows the scheme of the calculation area corresponding to the rest area (Figure 15), when the source of heat emission is specified – the place of cooking (stove) *T*=200 °C, the source of moisture emission is an artificial humidifier *Q*=100 g/m$^3$, the location is specified the employee's workplace.

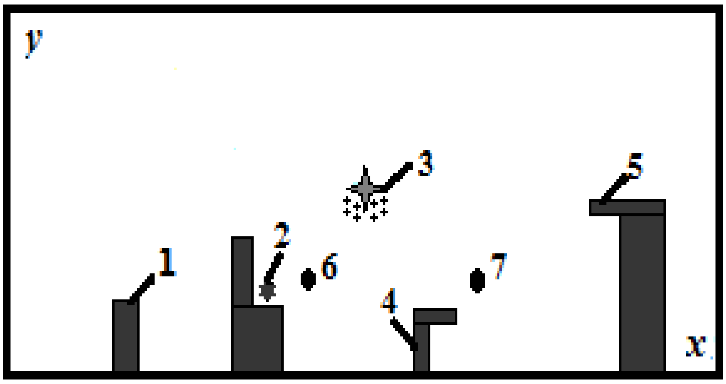


**Figure 16.** Calculation area: 1 – barrier, 2 – heat source (complex for preparing coffee and hot dishes), 3 – source of humidification, 4 – workplace, 5 – open cafe (canopy for visitors), 6, 7 – observation points [518]

Figure 17–18 shows the distribution of the temperature field (isotherm) and the concentration field of water droplets in the cross-section *y*=8 m.

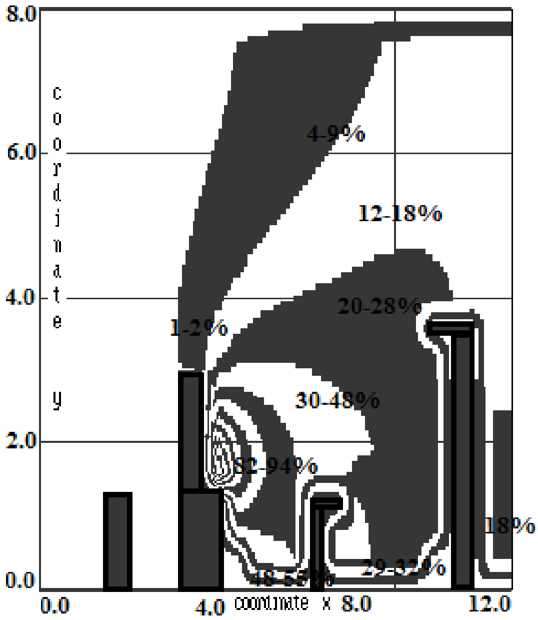


**Figure 17.** Temperature field distribution [518]

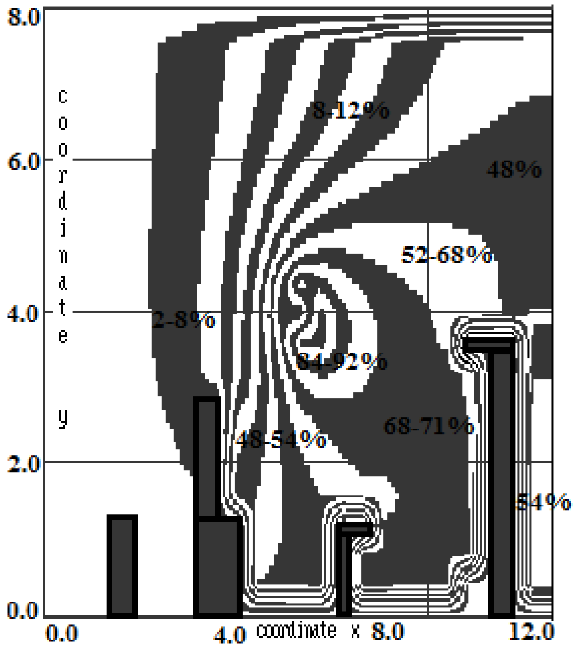


**Figure 18.** Distribution of the humidity field [518]

The value of humidity depending on the temperature, which are given in the Table 3 were calculated on the section located between points 6 and 7 (Fig. 16)

**Table 3.**

Value of humidity versus temperature

| Distance, cm | Humidity, % (experiment) | Humidity, % (numerically) | Humidity, g/m$^3$ (numerically) |
|---|---|---|---|
| 4.5 | 42.0 | 85.0 | 52.4 |
| 5.0 | 37.8 | 76.5 | 47.2 |
| 5.5 | 34.4 | 69.5 | 42.9 |
| 6.0 | 31.5 | 63.8 | 39.3 |
| 6.5 | 29.1 | 58.8 | 36.3 |
| 7.0 | 27.0 | 54.6 | 33.7 |
| 7.5 | 25.2 | 51.0 | 31.4 |
| 8.0 | 23.6 | 47.8 | 29.5 |
| 8.5 | 22.2 | 45.0 | 27.7 |
| 9.0 | 21.0 | 42.5 | 26.2 |
| 9.5 | 19.9 | 40.3 | 24.8 |
| 10.0 | 18.9 | 38.3 | 23.6 |

The optimal and permissible standards of temperature, relative humidity and air movement speed in the working area of industrial premises, depending on the time of year and the category of performed work (Ia, Ib, IIa, IIb, III) are given in the National Standard of Ukraine.

The working area is considered to be a space limited to a height of 2 m above the level of the floor or platform, where there are places of permanent or temporary stay of employees. The cold period of the year is characterized by an average daily outdoor temperature of +10°C and below, the warm period is characterized by a temperature above +10°C.

As the degree of work difficulty increases, the norms of optimal and permissible air temperature at permanent and non-permanent workplaces in cold and warm periods of the year decrease, and the normed values of air movement speed in these conditions, on the contrary, increase. This is so because the increase in physical stress and heat release require the intensification of heat exchange processes.

As an example, the following data from National Standard of Ukraine can be given. The optimal air temperature in the warm period of the year during light work of category Ia is 22–24°C, heavy work (category III) is 16–18°C. The permissible air temperature at permanent workplaces under these conditions during the performance of the specified works is 21–25°C and 13–19°C respectively.

If during the performance of light work of category Ia, the optimal and permissible speed of air movement is taken to be no more than 0.1 m/s, then during the performance of heavy work, the optimal speed of air movement is set to no more than 0.3 m/s and permissible – no more than 0. 5 m/s.

In the warm period of the year, the optimal and permissible standards of temperature and air movement speed are somewhat higher than in the cold period. An increase in air temperature norms in the warm period of the year is compensated by an increase in the speed of its movement. So, if during the performance of light work of category Ib in the cold period of the year, the optimal speed of its movement is no more than 0.1 m/s, then during the performance of the same work in the warm period of the year, the optimal speed is no more than 0.2 m/s.

The minimum permissible air temperature in the cold period of the year during heavy work at permanent and non-permanent workplaces is +12°C and +13°C.

respectively. The maximum permissible temperature is set for the warm period of the year during light work of category Ia: +28°C – at permanent workplaces, +30°C – at non-permanent workplaces. The minimum rate of air movement speed is 0.1 m/s, the maximum allowable is 0.2–0.6 m/s (during heavy work in the warm period of the year).

Both in the cold and in the warm period of the year, relative air humidity in the range of 40–60% is considered optimal. In the cold period of the year, the relative humidity of the air at permanent workplaces should not exceed 75%. In the warm period of the year, the permissible value of relative air humidity depends on the category of work performed. Thus, during light work of category Ia, the permissible relative humidity of air with a temperature of 28°C is 55% during heavy work it is 75% if the air temperature is 24°C and below.

Figures 19 – 20 present the distribution of temperature and relative humidity on the territory of an open cafe.

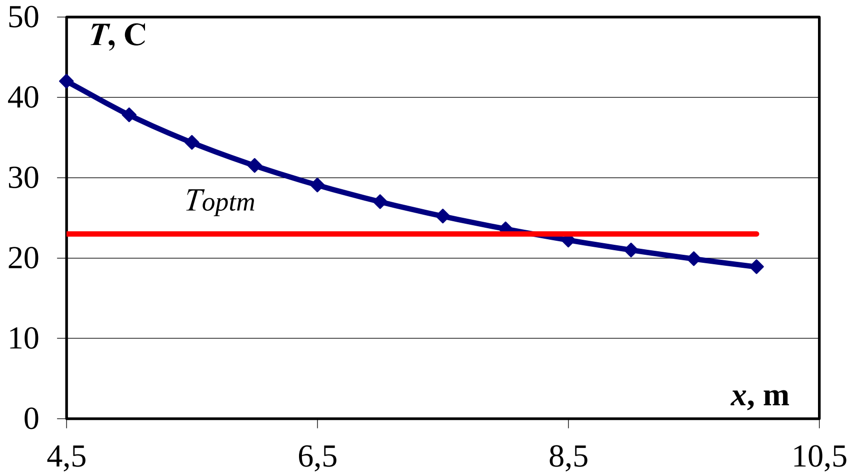


**Figure 19.** Temperature distribution on the territory of an open cafe

Figure 19 shows the temperature distribution on the territory of the cafe between points 6 and 7 (Fig. 16) and at a distance of 8.3 m the temperature corresponds to the optimal air temperature in the working area, i.e. cafe employees at a distance between 4.5 m and 8.3 m are in the zone of exceeding *Topt*.

Figure 20 shows the distribution of relative humidity in the cafe area between points 6 and 7 (Fig. 16) and at a distance of 6.2 m–9.4 m the relative humidity corresponds to the optimal value of humidity in the working area, but cafe employees at a distance between 4.5 m and 6.5 m are in the zone of excess relative air humidity.

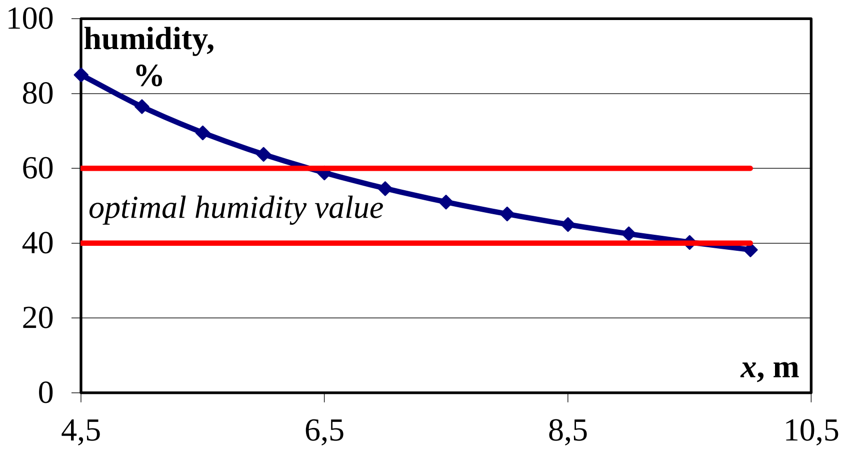


**Figure 20.** Distribution of relative humidity on the territory of an open cafe

A comprehensive method of evaluating microclimate parameters in work zones in open areas has been developed which allows predicting the level of humidity and temperature in work zones in the presence of the use of an artificial air humidifier.

**Conclusions.** The numerical and full-scale experimental studies conducted allowed us to solve the problem of forecasting microclimate parameters in the working area in an open area when using humidification. The conducted experimental and numerical studies confirmed the reliability of the developed forecast method with a numerical modeling error of 5–7%. A comprehensive method for evaluating microclimate parameters in work zones in open areas of industrial sites has been developed, which allows forecasting the wind regime, humidity and temperature in work zones in the presence of the use of an artificial air humidifier.