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Modernization of mechatronic smart windows system to counteract the spread of COVID-19

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Abstract. In terms of COVID-19 pandemic, the mechatronic system, essentially a smart window, supplemented with devices for interception and disinfection of drops and capsules with viruses and bacteria, both outside and inside. This allows preventing the ingress of infected aerosols into the room along with streams of air rising along the buildings and spreading inside it in the presence of infected people along with turbulent jets of air. With widespread use, the system helps to reduce the spread of infection, transmitted mainly by airborne droplets. The hardware for controlling the window system is performed on a board from the Arduino MEGA 2560 R3 ATMEGA16U2 family, two control boards with ten relays and ten sensor modules. Control program for the window system control circuit is written in the LabVIEW graphical programming environment (National Instrument USA).

1. Introduction

The pprerequisites for the development of the mechatronic system was environmental problems associated with urban air pollution with dust and burning from vehicles, thermal power plants, fires and natural dust storms, which have exacerbated in the last decade due to climate change due to air pollution by greenhouse gases and dust. The increase in temperature of the surface and near-surface air layers is associated not only with the greenhouse effect, but also with a decrease in the diffuse reflectivity of the surface and the near-surface air layer (albedo); in this connection, the Paris Agreement stipulates measures of the participating countries to limit the temperature increase, and not just emissions greenhouse gases. Thus, it is necessary not only to limit industrial emissions of dust and burning, but also to begin to clear the surface layers of the atmosphere from existing dust. Purification of harmful emissions directly in the sources of their occurrence has already been carried out since the beginning of the industrial revolution of the past millennium [1-5]. The use of concomitant renewable energy generators will help to save the consumer's electric and thermal energy and simultaneously solve its energy and living conditions. The use of renewable energy sources in urban conditions, only for generating electricity and heat, is unprofitable, since energy from traditional energy sources is much cheaper, and the infrastructure for transporting energy to consumers in cities has already been formed. In a situation where the incoming energy does not need to be used indoors, it can be accumulated in batteries or used in devices for capturing and fixing carbon dioxide and fine dust. The best option for such devices for building facades is greenhouses and vertical gardening [6-7], and in [8] the only effective way to deal with the greenhouse catastrophe on the planet is landscaping.

In connection with COVID-19 pandemic, the issue of reducing the spread of infection spreading by airborne droplets is an acute issue. In this case, the source of infection forms an aerosol cloud containing particles with infection, which retains the infectious ability for a certain time and is moved by air jets constantly present in living quarters and in the open. It is the window of the building that can be equipped with collectors and disinfectants of contaminated aerosols indoors and in an open atmosphere. Thus, upgraded mechatronic system [9-12], located in the window opening of the corresponding building, can act as an aerosol disinfector and reduce the spread of infection. Control functions can also be carried out by the Arduino Mega 2560 board, which runs on the ATmega2560 microcontroller. The board has 54 digital input/output (GPIO) ports, of which 15 can be used as PWM (PWM) outputs, 16 analogue inputs (a switch at the ADC input), 4 UART ports (a hardware serial port), and a crystal oscillator 16 MHz, USB connector, connector for power supply, connectors for connecting the programmer and reset button. The board has everything that is necessary to support the normal operation of the microcontroller.

2. Physical properties of infected droplet aerosols

Since the source of such an aerosol is a person, the aerosol particles consist of saliva or slime containing from 1% to 5% non-volatile compounds, including from 0.3% to 1% of mineral salts. When particles are eliminated from the human respiratory system into the surrounding air, the aerosol cloud is formed in it. It moves, delaminates and evaporates over time, depending on the state and type of particles. Studies have shown [13-19] that the diameter of droplets released into the environment during breathing, speech, screaming, singing, coughing, snoring and sneezing can be in the range of 0.5 μm - 200 μm and further the droplets dry out and decrease in size. Likelihood of a virus in a dry droplet of less than 1 μm is negligible [15], while drops of about 1-10 μm in size during speech, screaming and singing are most likely generated from saliva. When sneezing, possibly with coughing and snoring, from slime due to chemical properties similar to nosalslime with 5% content of non-volatile compounds (salt, mucins, proteins), aerosol drops also appear. Sedimentation rate of a spherical particle with a density of water in a stationary atmosphere is determined by the Stokes formula and decreases in proportion to the square of the particle radius. For a particle with a radius of 90 μm, this velocity is approximately 1 m/s, for 9 μm - 1 cm/s, for 0.9 μm - 0.1 mm/s. However, this does not mean that a particle with a diameter of 200 μm will reach the surface of the earth (from a height of 1.5 m) in 1 second. In an open area, ascending and descending flows are constantly present at a speed of 1-2 m / s, so that large particles can freeze at the same height and wait for their "victim" to draw a drop of infection with a stream of their breath. As a rule, the ascending air flows in the city are concentrated along the facades of the buildings, so that the infected aerosol generated on the sidewalk near the wall will climb the walls and can infect people standing at the open windows and on balconies or get through the ventilation into the living room. Indoors, there are turbulent jets with a speed of more than 1 m/s, which carry aerosol particles and prevent them from sticking to the floor, walls of various furniture. Situation is complicated by the fact that the particles still evaporate and form a dense and non-sticky shell. With prolonged evaporation at low humidity, the particles lose moisture so much that viruses and bacteria die. Since moisture is lost during droplet evaporation, the concentration of mucins and salt increases. At high salt concentrations, the osmotic pressure draws moisture from the virus capsoid. At an osmotic pressure of more than 25 MPa, due to the denaturation of proteins and nucleic acids, the life of microorganisms and even the most resistant to osmosis of mycelial fungi irreversibly [20]. Calculation of the osmotic pressure is carried out according to the Vant-Hoff formula for electrolytes:

$$p = i \cdot C \cdot R \cdot T \tag{1}$$

where i is the isotonic coefficient of the solution; C is the molar concentration of the solution, mol/m³; R is the universal gas constant; T is the thermodynamic temperature of the solution.

In terms of the concentration in grams of NaCl salt per milliliter of water (solvent), the deactivating virus osmotic pressure $p = 27$ MPa is obtained at a concentration of 0.33 g/ml and a temperature of 293 K. Thus, if the droplet dries to a state where the salt concentration reaches the specified value, the virus in it will be inactivated. Evaporation rate is determined by the Dalton formula and depends on the difference in humidity of saturated steam at the surface of the droplet and air humidity. Since the liquid is a solution, according to Raoult's law, the moisture content of saturated vapor in a drop decreases in proportion to the moles of the dissolved substance. For estimated moisture calculations, we can assume the weight percent of the solute and assume that the temperature of the droplet is equal to the temperature of the air. In this case, over a small temperature range from 0ºC to + 45ºC, the pressure of saturated water vapour $P_н$ can be estimated quadratically dependent on temperature:

$$P_h = (T - T_0)^2 \cdot \alpha_i \; [mbar] \tag{2}$$

where: T is the current temperature of the air and drops; T_0 - reference point temperature (-10 ºC); $\alpha_i = 0.03$ - coefficient of proportionality [mbar/deg^2].

Current partial air pressure can be found by multiplying P_h by the relative humidity of the air, $P_h \cdot e$, and the saturated vapor pressure at the droplet surface - by the fraction of the water remaining in the drop. Evaporation rate of a drop is proportional to the difference in these pressures. If the difference is positive, evaporation occurs, if the condensation is negative.

Ratio of the current pressure of saturated vapors of water over the solution to the pressure of saturated vapors of pure water ($AC(x)$ for slime, $DC(x)$ for salvia), depending on the proportion of impurities according to Raoul's law, is calculated from simple ratios:

$$AC(x) = \frac{x}{x+sli} \tag{3}$$

$$DC(x) = \frac{x}{x+slu} \tag{4}$$

where: x is the fraction of water remaining after evaporation in a drop; $sli = 5\%$ - the initial proportion of all impurities in the slime; $slu = 1\%$ - initial fraction of all impurities in saliva;

Concentration of NaCl salt in grams per milliliter of water during the evaporation process is determined by formulas 5 and 6, and in the slime the initial salt concentration is slightly higher than the physiological concentration in the blood plasma, i.e. about 1%, and in saliva it can drop to 0.3%.

$$Cpr(x) = \frac{1}{x} [g/ml] \tag{5}$$

$$Cpc(x) = \frac{0.3}{x} [g/ml] \tag{6}$$
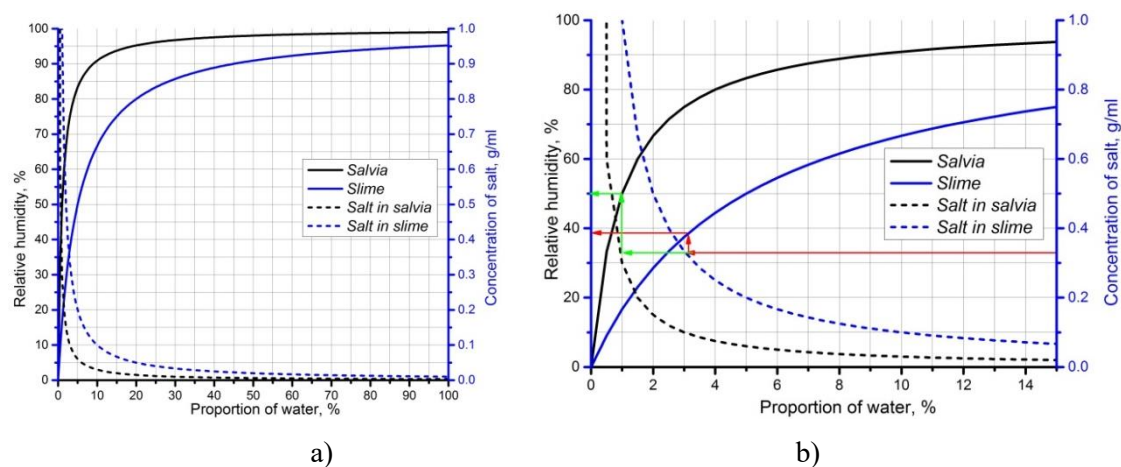

a)   b)

Figure 1. Relative pressure of saturated water vapour above the drop solution, depending on the percentage of water in the solution for slime and saliva.

Graphs of the relative pressure of saturated water vapour over the droplet solution, depending on the percentage of water in the solution for slime and saliva, are presented in figure 1 for the temperature of the drop and air $T = 293$ K.

As it can be seen from figure 1(b), if the relative humidity is more than 0.5 (50%), then the salt concentration does not reach the critical level after evaporation is stopped and the viruses inside the droplet remain viable even in saliva. In a drop of slime, the virus remains viable even at air humidity greater than 0.37 (37%). Thus, we can conclude that the evaporation of droplets of slime and saliva in the air with a relative humidity of more than 50% does not lead to inactivation of viruses. Moreover, at the end of the evaporation process, the outer layers of the droplet form a solid porous capsule that bounces off dry surfaces and is picked up by jets of air. Such droplets will retain the active form of the virus, as long as the temperature fluctuations do not denature the proteins or nucleic acids of the virus. In cold weather, the denaturation process can take weeks. In hot weather, in continental areas and indoors, especially with an air conditioner running, humidity can drop below 30%, and in this case, when the drops dry, all viruses will be inactivated. In this case, it is important to know: how long a drop will evaporate to achieve a critical salt concentration. To calculate this time, it is necessary to calculate the evaporation rate according to the Dalton formula. With estimated accuracy, this calculation is more convenient to carry out according to the formula of the VDI 2089 standard.

Then, dependence of the evaporation rate $Er(x)$ on the fraction of water x remaining in the drop of slime*x* can be written in the form of formulas (7)

Implementation of the hardware-software complex through the use of the computer audio subsystem gives scanning considerable flexibility in controlling the frequency of the electromagnetic field in the exciting circuit within the range from 100 Hz to 2 kHz.

$$Er(x) = k \cdot P_H \cdot (AC(x) - e) \cdot S(x) \qquad (7)$$

where: $k = 1.5 \cdot 10^{-6}$ reference coefficient of water evaporation [kg·(m^2· sec·mbar)]; e is the relative humidity;

$$S(x) = 2.28 \cdot [\pi \cdot V \cdot (x + sli) / 100]^{0.667}$$

Here $S(x)$ is the surface area expressed in terms of the initial volume V and the fraction of water in the drop solution.

Figure 2 shows the dependences of the evaporation rate of a droplet of saliva and slime with an initial diameter of 10 μm in ambient air with a relative humidity of 0.8 (80%) and 0.3 (30%). To calculate the drying rate of a droplet of saliva, instead of the parameter $sli = 5$, in the formula (7), substitute the parameter $slu = 1$, which corresponds to the fraction of non-volatile impurities of saliva.
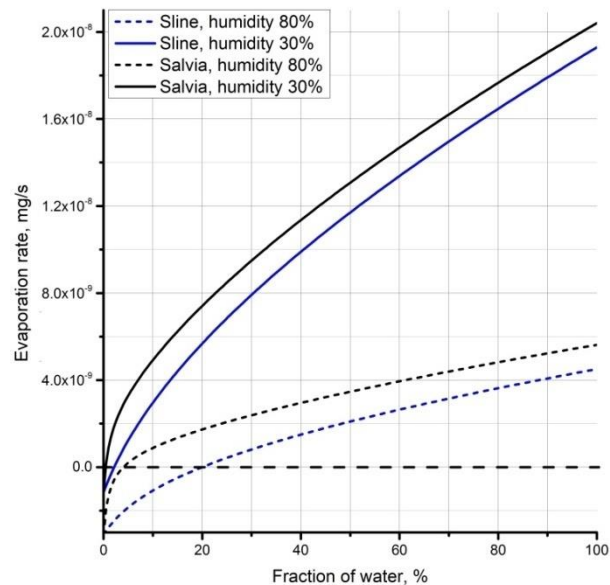
Figure 2. Mass evaporation rate of a droplet of slime and saliva with an initial droplet diameter of 10 μm at temperature T = 308 K.

Figure 2 shows that the dependence, with sufficient accuracy for the estimated calculations, can be linearly approximated. It makes no sense to look for the time after which drying will stop at high humidity, since the virus in the capsule will be active after drying, and its activity will persist for tens and hundreds of hours depending on air temperature, and windy "whirlpools" can accumulate them and keep their location . But to determine after what time the virus will be inactivated at low humidity will make sense. The average evaporation rate during linear approximation will be for a drop with a diameter of 10 μm for slime $9 \cdot 10^{-9}$, and for saliva $9.5 \cdot 10^{-9}$ mg/s, then the droplets at a temperature of 35° will dry and inactivate in 60 and 55 seconds, respectively. A drop of 100 microns in size, flying with jets of air, will dry for 600 seconds and 550 seconds, respectively, and during this time they can infect a person.

3. Smart window upgrade to counter the spread of viral infection
It was shown that particles of infected aerosols up to 100 microns in size, contrary to popular belief, do not settle on the floor, but, on the contrary, soar upward after ascending flows of turbulent jets. In cities on the streets, updrafts rise along the facades, taking with them an infected aerosol. In old buildings, air vortex analogs of whirlpools can form in balcony openings, in which the concentration of infected aerosol particles will accumulate. If a person entering the balcony gets into the vortex zone, the likelihood of infection increases. The smart window design [10, 11] provides a system for capturing uninfected dust from ascending streams using washable acrylic plates (figure 3).
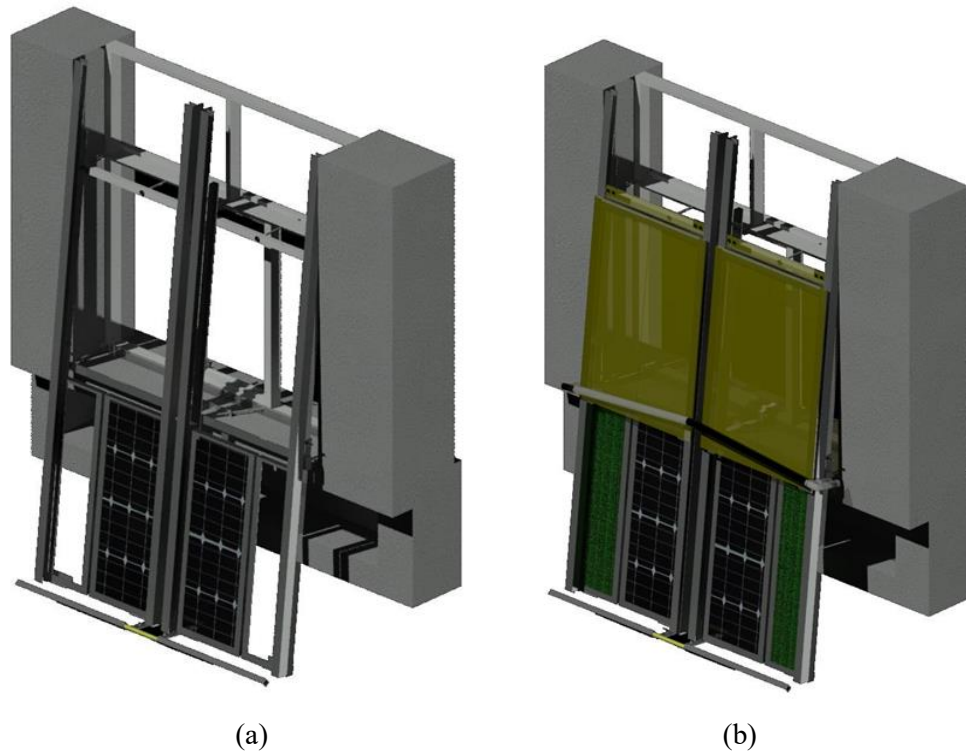
(a)　　　　　　　　　　　　　　　　(b)

Figure 3. Smart window mechatronic system design.

Main essence of modernization is the processing of an open dust collecting system into a cavity system with forced injection of air masses with aerosols into the cavity. It is necessary to equip the windows of buildings with traps of dust and particles of aerosols, carriers of viruses and bacteria so that they provide commercial attractiveness due to the greenhouse greening of window sills and other consumer structural properties. This will allow air disinfection indoors and outdoors and creation of jobs for the production of structures.
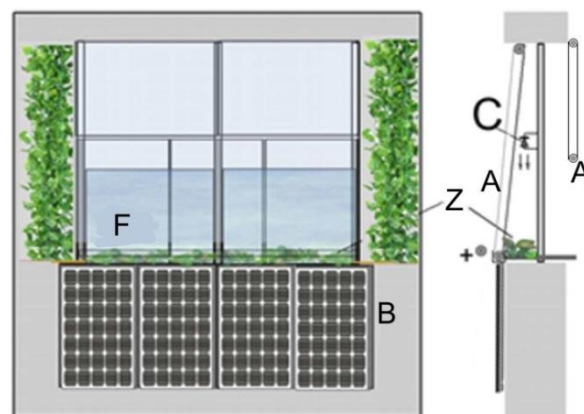

Figure 4. Smart window mechatronic system design.

In this case, not only the environmental goal of combating smog and infected aerosols is achieved, but also greenhouse gas emissions are reduced, the economic problems of the cost-effective use of alternative energy sources for both their producers and their consumers are solved. Accumulated photoelectric energy of batteries *B* (figure 4) will be used to power the electromechanical and disinfecting devices of window *A*, generate photosynthetic lighting *C* from plants *Z* and provide the premises with electric power in emergency situations. An innovative approach to cleaning and disinfecting the air by continuously removing aerosol particles over a vast area of building facades and windows using solar energy flows determines the novelty of the task. The system has been proposed to widely use rather simple devices for sterilizing air on the street and indoors, which remove suspended aerosol from suspended air. When talking, screaming, singing, snoring, coughing, sneezing, a person infected with the virus generates a fine aerosol, which, with high humidity and the presence of turbulent movements in the room or on the street, remains suspended and infected for a long time. Figure 5 schematically shows the design of such a device.
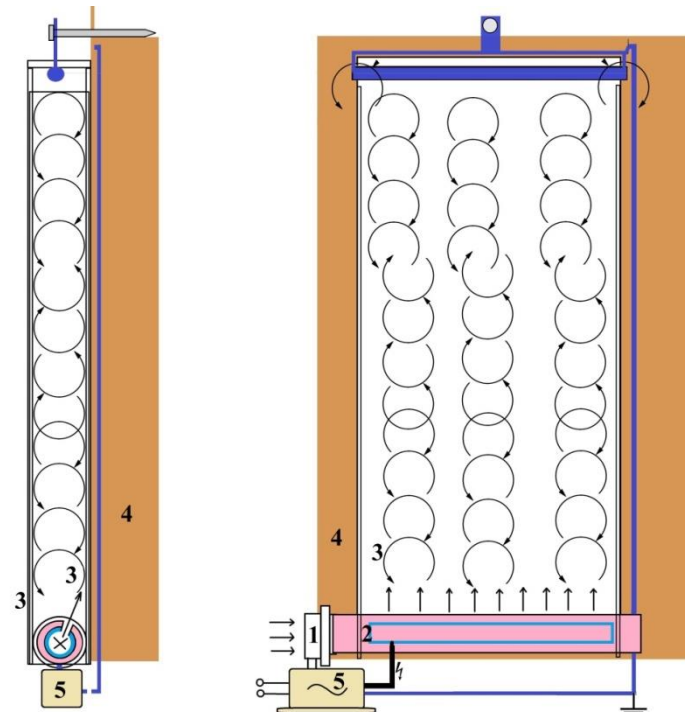

Figure 5. Schematic design of a device for catching and disinfecting aerosol particles: 1 – fan; 2 - charging tube; 3 - film or glass; 4 - wall or frame; 5 - electronic unit.

Fan 1 directs the air flow from the space of the person's location or route to the charging tube 2 of the aerosol particles with slots and then to the charged surface of the cavity from the film or glass 3, which removes dust and aerosol from the air stream. Subsequently, their surface is washed with a disinfectant solution. Part of the film and glass can serve as a sensor for analyzing the contamination of a public place or dusty air. The device can be glued or hung on the wall 4 in a room or a corridor, or use window glass instead of a film.

Control program of the window system is written in a graphical programming environment LabVIEW (National Instrument, USA), which allows flexible debugging the program, testing the hardware and software of the window system control circuit and the whole system. After everything has been debugged, it is possible (if necessary) using the compiler to convert the program into firmware codes for the Arduino board. This approach is considered the most optimal. The Arduino Mega 2560 board with the ATmega2560 microcontroller has all the necessary arsenal of properties to process signals from position sensors of structural units, sensors of the properties of the external and

internal environment of the room with high performance and monitor the current time. The ATmega2560 microcontroller has 256 kilobytes of program memory (FLASH) on board, of which 8 kilobytes are occupied under the code loader (Arduino UART loader). Thus, the user can use 248 kilobytes of program memory for their purposes. RAM is 8 kilobytes. The microcontroller also has a non-volatile memory (EEPROM) of 4 kilobytes, the values in which are stored between power offs. The EEPROM memory can store various configuration data of the programmable system. The board is compatible with most shields designed for Arduino Duemilanove or Arduino Diecimila boards. Program debugging is performed on a separate stand of the current model. The debug location is shown in figure 6.
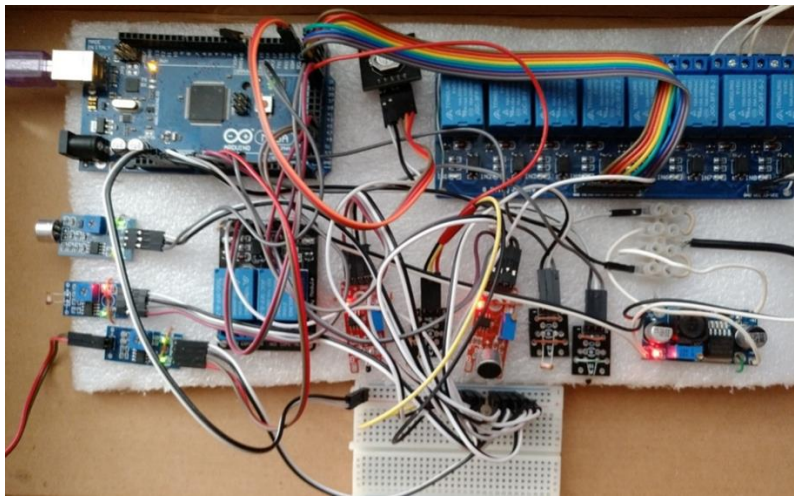

Figure 6. Window System Control Scheme.

4. Conclusion
In many large cities, smog was also possible, especially in the light of the coronavirus pandemic, causing irreparable damage to the city's economy and the health of its inhabitants. The latest pandemic shows the severity of the problem of dustiness and contamination of cities. The use of the mechatronic smart window system contributes to efforts to clean and disinfect indoor and city air pools. The functioning of such a multidisciplinary system is impossible without enhanced digitalization and the use of control controllers.

References
[1] Aliev G M-A 1986 *Technique of dust collection and purification of industrial gases* (Moscow: Publisher "Metallurgy")
[2] Ladygichev M G and Berner G Ya 2004 *Foreign and domestic equipment for gas purification; Ref. Edition* (Moscow: Publisher "Heat engineer")
[3] Yushin V V, Popov V M, Kukin P P and others 2005 *Technique and technology of air protection. Textbook Allowance* (Moscow: Publisher "Higher school")
[4] Vetoshkin A G 2005 *Dust cleaning processes and apparatuses. Tutorial*. (Penza: Publishing House of Penza State University)
[5] Vetoshkin A G 2019 *Environmental engineering. from harmful emissions. Tutorial. 2nd ed., rev. and add.* (Moscow: Publisher "Infra-Engineering")
[6] Bustami R A, Belusko M, Ward J and Beecham S 2018 *Vertical greenery systems: A systematic review of research trends* (Publisher "Building and Environment")
[7] Perini K, Ottelé M, Haas E M and Raiteri R 2013 *Urban Ecosyst.* **16** 265–277
[8] Bastin J, Finegold Y, Garcia C, Mollicone D, Rezende M, Routh D, Zohner C and Crowther T

2019 *Science* **365(6448)** 76-79

[9]   Mikhailov L, Mikhailova S, Ismailova G and Sokolov S 2017 *Mediterranean Green Buildings & Renewable Energy Ali Sayigh (Editor)* (Springer International Publishing)

[10] Mikhailov L V, Sidlyarov A M, Gabdulova N S, Zhalilov T M, Kenes N S and Zhetibaeva Zh G 2018 *High-performance computing systems and technologies* **1 (8)** 172-176

[11] Mikhailov L V, Sokolov A S, Mikhailova S L, Ersayyn R Zh, Ismaylova G A and Zhetybaeva Zh G 2019 *High-performance computing systems and technologies* **3 (1)** 210-217

[12] Mikhailov L, Mikhailova S, Ismailova G, Yersaiyn R, Kenes N, Lavrishev O and Nikulin V 2019 *Proc. of INESS 2019 "Materials Today"*

[13] Asadi S, Wexler A, Cappa C, Barreda S, Bouvier N M & Ristenpart W D 2019 *Scientific Reports* **9(2348)**

[14] Dboukaand T and Drikakis D 2020 *Physics of Fluids* **32** 053310

[15] Stadnytskyi V, Bax C, Bax A and Anfinrud P 2020 *The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission.*

[16] Chan J F-W et al 2020 *J. Clin. Microbiol.* **58** e00310-20

[17] Wölfel R et al 2020 *Nature* doi:10.1038/s41586-020-2196-x

[18] Anfinrud P, Stadnytskyi V, Bax C E and Bax A 2020 *N. Engl. J. Med.* doi:10.1056/NEJMc2007800

[19] Rothe C et al 2020 *N. Engl. J. Med.* **382** 970–971

[20] Vorobyov A A 2015 *Medical Microbiology, Virology and Immunology: Textbook* (Moscow: Publisher "MIA") ISBN: 9999908926