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Meteotron for the City, Powered by Solar Energy

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Abstract. This article deals with the problem of artificial ventilation of urban intersections. The need to find solutions to this problem is caused by the growth of urban air pollution due to the ever-increasing emissions from industry and transport in the presence of inversions in the atmosphere over the city. As a result of the analysis of existing methods of local influence on weather conditions, a method was chosen to create an upward flow of heated air. A basic design of the meteotron is proposed in the form of a high chimney, for heating which solar heaters are used to create a temperature gradient. Preliminary calculations showed that with a specific power of solar heaters of 250 W/m2, the total power of the meteotron will be 375,000 W, which will create a temperature difference of 4.1 °C. The city meteotron will improve air circulation and reduce the concentration of harmful substances at urban intersections.

INTRODUCTION

At present, climate change, population growth, the development of industry, transport and agriculture, as well as the growth of cities cause a number of climatic and meteorological problems mankind has to face.

These problems include the following:

- lack of fresh water;
- the need for ventilation of quarries, cities, etc.
- the need for dispersion of fogs, smogs, etc.
- creating a microclimate over the fields.

Ways to solve these problems can be divided into:

1. Large-scale intervention in the natural system of weather formation (solving the problem of obtaining fresh water with the help of artificial precipitation)
2. Ventilation of relatively small objects.

The solution for all of these problems is to mix one or another amount of air masses.

The necessary energy required to solve these problems can be obtained either by burning fuel or by solar radiation. In some cases, the mixing of air masses can be carried out by mechanical sources (aircraft and helicopter propellers, fans, etc.).

All methods and devices for the artificial movement of air masses are based on giving a certain column of air a vertical upward speed. An increase in the vertical air velocity in the initial section can be achieved by a significant initial overheating of the air in relation to the environment. The obvious advantage of heated jets from thermal sources over jets generated by mechanical sources in a stable atmosphere is as follows. As pressure decreases with altitude, the temperature of the rising air decreases.

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If unheated air rises, its temperature becomes lower than the surrounding one, and, as heavier, falls down again.

Superheated air rises to the height when its temperature is equal to the ambient temperature, and it no longer falls down in a given time interval [1].

Consider ways to obtain convective motions in the air due to fuel combustion.

The creation of a favorable microclimate in limited areas is described in the works of many authors and based on the use of powerful heat sources to create vertical air flows.

In ancient times, it was found that convective clouds and precipitation often form over powerful heat sources, which are not in the environment.

Such heat sources that generate convective clouds and precipitation are forest fires, active volcanoes, mountain peaks heated by the sun, “heat islands” that form over large cities, nuclear power plants, oil refineries and thermal power plants.

This is due to the fact that the air heated above the heat sources becomes lighter than the surrounding air and rises, stimulating the development of thermal convection and the formation of clouds, which can sometimes even produce heavy rainfall in conditions where natural clouds and precipitation do not form without such heat sources. Therefore, all known methods of creating an artificial microclimate are based on the creation of artificial heat sources.

Active influences on atmospheric processes, ventilation of large-scale areas such as open quarries, cuts, cities, airfields, and the creation of artificial ascending convective movements in the atmosphere are accompanied by high energy costs [1, 2].

The technique of artificial creating of updrafts due to the energy released during the combustion of fuel was used in South America and Equatorial Africa when setting fire to the prairie and savannah to form cumulus clouds.

This idea was used by the French scientist Dessens [1]. The installation designed by him (meteotron), representing in a simplified form a set of burners placed along concentric circles, was installed on a hill.

The heating of the lower layers of air was carried out due to the combustion of diesel fuel in the free atmosphere at a flow rate of 1 tonna/min, while the calculated thermal power of the installation was 10^5–10^6 kW, which is comparable to solar insolation received by 1 km^2 of the Earth’s surface. Since the area occupied by the burners of the meteotron was approximately 100 times smaller, the local heating of the surface layer of air during the operation of the meteotron significantly exceeded the natural heating. In some experiments, the appearance of clouds and precipitation in the form of rain was observed [3, 4].

The first known “FIDO” meteotron type system, consisting of two parallel pipelines with nozzles on both sides of the airfield runway, was used in England in 1943 at one of the military airfields to combat fogs and improve landing conditions for aircraft. Similar installations were tested at Orly Airport in France and Cuba. In the Soviet Union, an installation based on RD-3M turbojet engines was developed. Ascending forced convective jets were created due to initial overheating (about 1,000 K), but to a greater extent due to their high initial velocity (~500 m/s). Vertical jets of air from such high-velocity and high-temperature sources have been used with varying degrees of success to clean coal and ore open pits from contamination [5, 6, 7].

All known meteotron-type thermal installations for studying the possibility of creating a microclimate are united by the method of heat release by burning large amounts of fuel in the surface layer of the atmosphere. The thermal power of known installations approaches $2 \cdot 10^9$ W, and during the operation of such installations a large amount of soot is formed, which, according to [8], absorbs short-wave solar radiation, further contributing to the rise of the jet.

Of interest is the method [9], which provides for a multilevel system of influence on inversion layers in the troposphere.

The impact is carried out by introducing a group of autonomous heat sources into the desired area of the atmosphere spatially in the form of circles of different diameters. Heat sources are high-energy ammunition, for example, plasma-optical action (caliber 30 mm, explosive content 0.02 ... 0.04 kg) [10]. During the explosion of ammunition, dense plasma is injected into the atmosphere, as well as intense optical and thermal radiation.

Solar heaters are widely used to destroy atmospheric temperature inversion with the help of updrafts in order to ventilate objects.

The sun is a powerful, environmentally friendly and ubiquitous source of energy that shapes the weather in natural conditions. In cloudy weather at noon, the heating of the blackened surface from all sides is about 1 kW/m2. Let's consider solar meteotrons used for airing quarries. The use of traditional means of artificial ventilation - aircraft and helicopter propellers, turbines, thermal installations - in deep and ultra-deep quarries is often problematic due to their high cost, bulkiness, interference with technological operations, high energy and fuel consumption. The fuel burned in the installations, as well as high speeds of ventilation jets blowing dust off the sides, can, on the contrary, worsen the state of the quarrey atmosphere, and the need to remove the installations to a safe distance during blasting leads to an increase in operating costs [7].

Particular attention should be paid to improving the air quality of large cities. In our time, the time of the steady growth of various industries and transport, the air becomes more and more polluted. First of all, this applies to large cities, where road transport literally flooded the streets. No measures to improve the design of the car and the use of new types of fuel cannot yet help to cope with the ever-increasing amount of exhaust gases. Their highest concentration is above the carriageway of streets, and especially in the area of regulated intersections, as well as busy bus stops [11, 12].

The entire mass of exhaust gases mainly covers the area where people are permanently located.

Polluted air is difficult to tolerate in calm weather, especially in the presence of surface temperature inversions, which are most often formed on calm nights (and sometimes during the day in winter), as a result of intense heat radiation from the earth's surface.

In large cities, densely built up and saturated with transport, there is an increase in temperature compared to suburban areas [13].

As a result, “heat islands” are created in the atmosphere above cities, which not only cause discomfort for the population, but also prevent the rapid dissipation of exhaust gases and dust particles due to temperature inversion. As a result, the health of urban residents is at additional risk [14, 15]. WHO estimates that 91% of urban residents breathe polluted air. Improving the air quality of settlements is one of the targets of SDG 11 "Sustainable cities and towns". The sustainable development goals have also been adopted in Uzbekistan. At the same time, air quality in the cities of Uzbekistan does not always correspond to a favorable level.

Maintaining the health of the population requires the provision of a normal microclimate. There are proposals to create zones protected by domes in the city [16], but such solutions require enormous financial costs and look unrealistic, especially for developing countries.

The methods and devices discussed above for ventilating objects are not very suitable for urban conditions. Indeed, a device for obtaining ascending jets by burning fuel, in addition to costs, will itself be a source of harmful emissions.

The purpose of this work is to search for the possibilities of artificial ventilation of local areas of urban areas.

MATERIALS AND METHODS

Study Area

The studies were carried out for the conditions of Tashkent, the capital of the Republic of Uzbekistan.

Tashkent is located in the zone of subtropical continental climate. The average annual temperature is +14.8 °C, the maximum summer temperature can reach 44.6 °C. According to Uzhydromet observations, the climate of Tashkent has also become warmer due to the growth of the city itself and, as a result, the strengthening of the warming effect of the infrastructure of the metropolis. From 1933 to 2006, the warming effect of the growth of Tashkent itself on its own climate was more than +0.4 degrees. However, here the warming effect turned out to be more noticeable in summer, when the temperature increase was +0.6 degrees.

Tashkent accounts for the largest share in the structure of industrial output of the Republic of Uzbekistan - 19.2% of the republican industrial output. Accordingly, the transport sector is developed: 447,900 vehicles are operated in Tashkent.

The abundance of industry and transport contributes to air pollution. The air quality in Tashkent corresponds to the “Unhealthy” rating [17].

Prerequisites for the Choice of the Design of the Meteotron

For local improvement of the atmosphere on city streets and intersections, obviously, methods similar to the ventilation of quarries should be used. This solution is based on the fact that the artificial relief created by city buildings forms closed spaces like quarries or canyons [18]. When developing the design, we will consider only those options that use solar energy.

There are technical solutions for intensifying the natural ventilation of quarries by using the heat of the sun's rays [6].

For example, ventilation of quarries can be carried out with the help of solar meteotrons, which are areas of the earth's surface covered with asphalt or black fabric, or black blocks, which absorb solar radiation well [19].

Another version of the solar meteotron [20] is a blackened screen raised above the ground, surrounded by a system of rotary mirrors that focus solar energy onto the screen.

There are known methods for destroying the temperature inversion layer and scattering the concentration of aerosols in the air by convective jets created by balloons with a blackened side surface located above the upper boundary of the inversion layer [21, 22].

More perfect can be considered the method of active influences on the inversion layer, based on the creation of an ascending air flow in the atmosphere [23], heated at several levels from the blackened surface heated by the sun of a multi-tiered system of tethered balloons (heliators). To increase heat release due to condensation processes, grounded electron emitters are fixed on the tiers, which corona in the Earth's electric field.

In cloudy weather, a system of garlands of tethered balloons (aerostats) is launched into the atmosphere in the form of several tiers located one above the other (Fig. 1). The surfaces of the cylinders made of blackened material heated by the Sun give off heat to the surrounding air, creating an ascending free convective flow.

The rising air reaches the next tier of balloons (balloons), where additional heating occurs; the process is repeated until the required height is reached. The blackened surfaces of all raised tiers are heated by the sun and create updrafts in the atmosphere. The distance between the tiers is chosen so that the air, not having time to cool down to the ambient temperature, reaches the next tier of balloons (aerostats). The heating process is repeated on all tiers, up to the top. An ascending flow of air heated under controlled conditions is formed along the axis of the installation in the form of a flexible column of the required height.

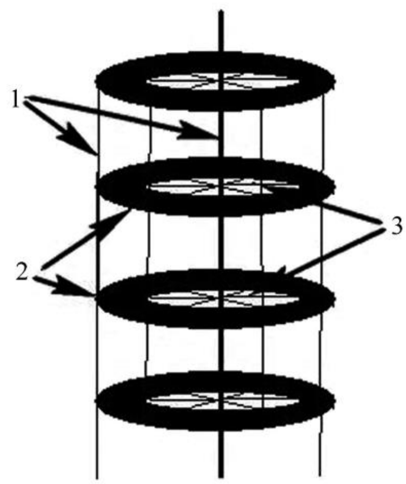

FIGURE 1. Scheme of the heliator [23].
1 - power cables, one cable is grounded, 2 – blackened helium cylinders, 3 - conductive grounded spokes.

As a result, the surface zone is cleaned from pollution, and these pollution, being lifted up, together with ions play a positive role as condensation centers. The dimensions of the tiers, their number, the distances between them, the height of the lower and upper ones are determined by the weather conditions and the task (artificial precipitation, air purification, etc.). The disadvantages of the device include bulkiness, the need for a large amount of helium and the difficulty of working with a side wind. Such devices are proposed to be used in agriculture to create a microclimate over the fields [24]

Solar meteotrons, which are blackened surfaces, are unacceptable for urban conditions due to the need for large areas. Heliators, as mentioned above, require a large flow of helium and are unstable in windy weather. Therefore, it is obvious that the urban meteortron must not only work at the expense of solar energy, but also have a stable and sufficiently rigid structure.

Thus, the basis of the device should be a high chimney, with the maximum possible number of solar heaters installed on it.

Calculation of Technical Indicators of the Meteotron

The purpose of the calculation is to determine the temperature difference in the jet and the ambient air, which ensures the rise of the jet, as well as the second water flow for pump selection.

The total power P of the meteotron can be determined from the expression:

$$P = q \cdot S\,, \qquad W \tag{1}$$

where q is the specific power of solar heaters W/m^2, S is the total area of solar heaters.

The energy of the second mass of the air jet at the lower level is the sum of its thermal and kinetic energy. Equating the power of the meteotron with the energy of the second mass of the jet [2], we obtain the equation:

$$P = \pi R_0^2 \rho_0 w_0 \left(\Delta T_0 c_p + \frac{w_0^2}{2} \right) \tag{2}$$

where R_0 is the air jet radius; ρ_0 – air density (ρ_0=1.2 kg/m^3); c_p is the heat capacity of air (c_p = 1,000 J/(kg·deg)); w_0 is the air jet velocity; ΔT_0 is the temperature difference in the jet and in the atmosphere.

Let's solve the equation (2) for ΔT_0:

$$\Delta T_0 = \frac{P - \frac{\pi R_0^2 \rho_0 w_0^3}{2}}{\pi R_0^2 \rho_0 w_0 c_p} \tag{3}$$

The second water consumption was determined from the condition of energy conservation:

$$Q_{air} = Q_{water};\ Q_{air} = c_{air} \cdot m_{air} \cdot \Delta T_0 \ ; \quad Q_{water} = c_{water} \cdot m_{water} \cdot \Delta t \tag{4}$$

Where Δt is the difference between the initial and final water temperatures; m_{air}, m_{water} - second mass of air and water, respectively.

Substituting the necessary values into expressions (4), we obtain:

$$\pi R_0^2 \rho_0 w_0 c_{air} \Delta T_0 = c_{wat} \cdot m_{wat} \cdot \Delta t \tag{5}$$

Where does a second mass of water come from:

$$m_{wat} = \frac{\pi R_0^2 \rho_0 w_0 c_{air} \Delta T_0}{c_{wat} \cdot \Delta t} \tag{6}$$

RESULTS

Based on the results of the analysis of the existing versions of the weather torch for urban intersections, the design of the exhaust pipe was chosen (Fig. 2). The entire surface of the pipe is covered with solar heating panels. Instead of a burner, a powerful heater is placed at the entrance to the pipe, in which water from the solar heaters circulates. The use of water as a heat carrier is justified by the fact that it has a significantly greater thermal inertia than air and will allow the installation to operate at night.

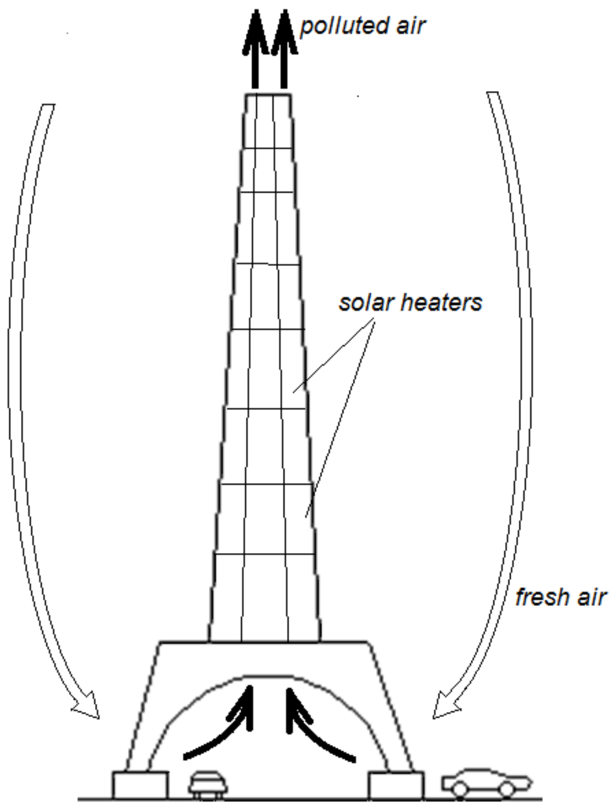

FIGURE 2. Street meteotron.

The heated air rushes up the pipe, and together with it harmful pollutants will be carried to a height of 50-60m. In place of the mass carried away, cleaner air will flow into the surface layer. That it will be possible to somewhat improve the weather conditions of the street.

Let's set the following parameters of the meteotron for placement at the intersection: the diameter of the pipe at the base is approximately 10m and the height is 50...60m. The choice of height is dictated by the need to bring the exhaust pipe out of the city canyon. With such dimensions, about 1,500 m^2 of solar heaters can be placed on the chimney itself and various superstructures.

Taking the specific power of solar heaters q = 250 W/m^2 [25], we determine the total power P of the meteotron by formula (1):

$$P = q \cdot S = 375{,}000\ W$$

In summer, the Sun in the territory of Tashkent can provide up to 600 W/m^2, while the power of solar heaters will be 900,000 W.

The temperature difference ΔT_0 in the jet and in the atmosphere was determined by equation (3) with the following initial data: air jet radius R_0 = 5m; air density ρ_0=1.2 kg/m^3; heat capacity of air c_p = 1,000 J/(kg·deg); we take the air jet velocity w_0 = 1m/s

$$\Delta T_0 = \frac{P - \dfrac{\pi R_0^2 \rho_0 w_0^3}{2}}{\pi R_0^2 \rho_0 w_0 c_p} = \frac{375{,}000 - \dfrac{3.14 \cdot 5^2 \cdot 1.2 \cdot 1^3}{2}}{3.14 \cdot 5^2 \cdot 1.2 \cdot 1 \cdot 1{,}000} \approx 4.1\ ^oC$$

The second water flow was determined by the formula (6):

$$m_{water} = \frac{\pi R_0^2 \rho_0 w_0 c_{air} \Delta T_0}{c_{water} \cdot \Delta t} = \frac{3.14 \cdot 5^2 \cdot 1.2 \cdot 1 \cdot 1{,}000 \cdot 4.1}{4{,}200 \cdot 10} = 10 \quad kg/\text{s}$$

Thus, the operation of the solar heating system can be provided by a conventional centrifugal pump.

DISCUSSION

The data obtained allow us to state that the proposed design is able to ensure the removal of polluted air from the breathing zone on a local scale.

The method of ventilation of urban areas proposed by us will require less costs than the redevelopment of urban development, as proposed, for example, in [18, 26].

The operability of the proposed design indirectly confirms the experience of using devices similar in principle of operation - solar chimneys, successfully used for ventilation of buildings. In solar chimneys, the air flow is created in a vertical shaft due to the temperature difference between the upper and lower parts of the shafts, and the upper part of the shaft is heated by solar radiation [27].

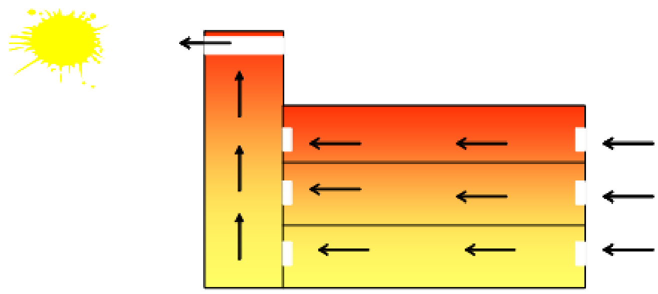

FIGURE 3. Solar chimney [27].

CONCLUSION

The developed basic design of the meteotron will improve air circulation at urban intersections and reduce the concentration of harmful substances in the breathing zone of the population.

Further research should be aimed at testing the proposed design in real conditions, determining its optimal dimensions and evaluating strength and stability.

For more efficient cleaning of urban air, one should consider placing the “exhaust” part of the “petals” pipe made of photocatalytic concrete. As is known [28], concrete with the addition of titanium dioxide under the action of sunlight decomposes any pollution on its surface and even cleans the surrounding air from automobile exhaust gases. With its use, the meteotron will perform not only the function of removing polluted air from the breathing zone, but also cleaning it.

In addition to the main purpose, the meteotron can be used to place observation platforms, restaurants, shops, etc. With a successful architectural solution, the meteotron can become a decoration of the city.

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