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The estimation and reduction of risks caused by air pollution in cities

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Abstract: The increase in summer temperatures is intensifying and causing the rise of air pollution by photochemical transformation. The main source of pollution in cities are vehicles. Calculations of a convective jet from the warm surface of intersections and overpasses have been performed and the secondary formaldehyde contamination by photochemical transformations was estimated. It was shown that the non-carcinogenic risk is significantly increased with the concentration. At temperatures above 30°C, the non-carcinogenic risk is more than 10 (significant) and requires in-depth studies of the harmful influences. Carcinogenic risk ranges from the median to acceptable and requires dynamic control and in-depth studies. Reducing the risk is possible by "green" design: "green" roofs, vertical greening, facade blocks, etc. Using phytoncide plants destroys the pathogenic microflora and improves the microclimate of the premises. Proposed is an assortment of plants suitable for medical and educational buildings within a continental climate area.

Keywords: atmosphere pollution, formaldehyde, photochemical transformation, "green" structures, phytoncide plant

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Introduction

In recent years, due to global warming, there has been an increase in the average daily temperature in the summer with a neutral (steady) atmosphere. The monitoring of atmospheric air pollution in urban areas indicates a sharp increase in concentrations of pollutants due to photochemical transformations in the atmosphere.

As a result, the concentration of formaldehyde in the air as a secondary pollutant can equal between 5-8 MAC. According to the World Health Organization (WHO), about 13% of premature deaths can be prevented by improving air quality. In addition, measures to reduce the pollution of urban air will reduce emissions of short-term climate pollutants (Baklanov, 2012; Marlier et al., 2016; Solomon et al., 2007).

It is proven by the research of many authors that for a number of large cities in developing countries the main source of pollution is motor transport. The growing dependence on personal vehicles in the context of global climate change leads to an increase of atmospheric air pollution and an increased risk to public health, especially on the border of residential developments. In this paper, the authors assess the mutual influence of temperature increase on urbanized territories, secondary pollution of atmospheric air by formaldehyde from motor vehicles as a result of photochemical transformations and risks to the health of the population from this contamination.

One way of improving the environmental safety of cities and reducing the risks of morbidity in the population from atmospheric air pollution is the use of "green" builds in conjunction with plants. They are able to absorb CO_2 and reduce the temperature due to the "cooling effect" of the plants, as well as improve the microclimate of residential premises on the border of residential buildings and highway.

1. The latest research and publications

A large number of works are devoted to the formation of urban climatic systems, and consider anthropogenic flows over thermal spots in the city. These increase the temperature and form the so-called "islands of heat" and "urban stone pipes". Several authors have written about the issue of atmospheric air pollution in urban environments as a result of photochemical transformations and the impact of this pollution on human health (Cassiani et al., 2013; Hodzic et al., 2009; Hodzic et al., 2010; Hallquist et al., 2009; Kleinman et al., 2008). An increase in the rate of man-made streams over the city, especially in developing countries, including Ukraine, is also due to an increase in the number of motor vehicles that work on gasoline or diesel fuel. Recently, traffic jams at large intersections and overpasses have become commonplace in urban areas and make a significant contribution to the air quality in man-made heat fluxes. The Department of Ecology and Natural Resources in the city of Kyiv stated that during recent years the main contribution to air pollution was registered from motor vehicles, which accounts for more than 70% of the total amount of atmospheric emissions in the city (Regional report, 2017).

In order to make managerial decisions about the importance of the risk to the health of a population, which is constantly in the zone of polluted air, it is necessary to have apparatus that can calculate the concentration of formaldehyde.

The mathematical model for estimating the atmospheric air pollution of urobocenoses, depending on climatic conditions and the amount of hydrocarbon emission on automobile overpasses, has been widely tested in Kyiv. A comparison of measured values of secondary pollution with formaldehyde in atmospheric air with maximum values gives an error of 5%, while the mean monthly values of formaldehyde in the surface layer give a difference up to +20%. This error is explained by the formation of secondary contamination with formaldehyde at a distance of 200 m from the surface and above.

The resulting method provides an opportunity to determine the environmental risk for the population from the secondary pollution of atmospheric air with formaldehyde with the subsequent provision of operational information the government needs to optimize measures for reducing the impact of vehicles in urban conditions.

2. The purpose and method of the research

The purpose of this study is to assess the risk to the health of the population from the secondary pollution of atmospheric air with formaldehyde on road overpasses under high-temperature conditions and to reduce the negative impact on the environment and people in the areas of "green buildings".

To achieve the goal, the following tasks were undertaken:

- an analysis of the formaldehyde pollution of atmospheric air in the urban environment from the emissions of vehicles stuck in traffic on overpasses in neutral atmospheric conditions and elevated temperatures;
- identification of the risks to public health by existing methods and their relationship with the temperature conditions of the area;
- an analysis of the risk reduction for public health by implementing "green" designs.

3. Risk estimation due to secondary formaldehyde contamination

3.1. Estimation of the concentration of formaldehyde

Based on the mathematical model developed by the authors (Voloshkina, 2018) for determining the amount of hydrocarbon emission from road transport over an overpass and the concentration of formaldehyde, a convenient atmospheric air pollution calculator has been developed for MS Excel 2016. This calculation tool allows the determination of the relationship between the concentration of formaldehyde in air and the temperature conditions for a certain amount of transport on an overpass, the amount of solar radiation in the area and the area of the heated surface. The calculator is based on the authors' formula for formaldehyde concentration that is obtained from the mathematical model of convection (Sipakov et al., 2018) [mg/m^3]:

$$C_f = \frac{A \cdot n}{D\left(R_p + R_n + R_{car}\right)^{0.33}} e^{8.959 - \frac{3784}{T}} \tag{1}$$

where:

A - factor that indicates the amount of pollution and heat per square meter of the warm surface during one time unit, for Kyiv A = 73.7 mg/(KJ/m^2);

n - the number of lanes;

D - the equivalent diameter (by area) of the warm surface;

R_p, R_n, R_{car} - scattered, direct solar radiation and the heat from total amount of cars on the heated area [KJ/m^2];

T - the air temperature in the surface layer [K].

Figure 1a shows the linear dependence for the conditions of Kyiv and the total solar radiation in July for this area. Calculations for other large cities of Ukraine with different solar radiation indices and input parameters showed a close correlation between these values.

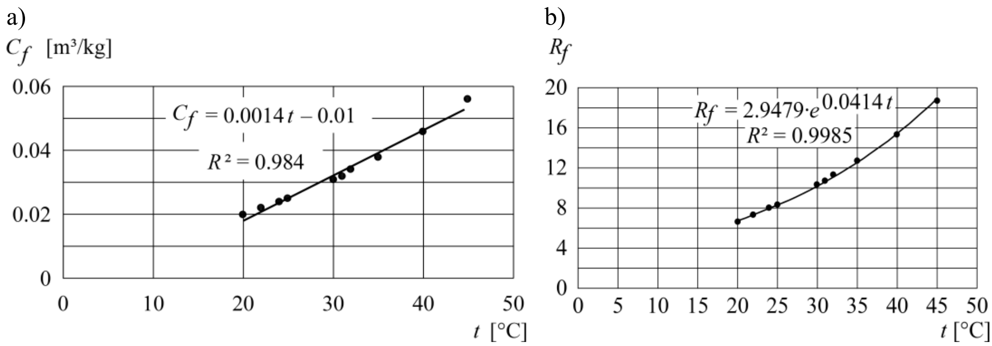

Fig. 1. Dependence between the concentration C_f [m^3/kg] of formaldehyde in air and the non-carcinogenic risk value R_f at steady meteorological conditions on the air temperature t [°C]. The calculation is made by the authors for the Darnytsia square in Kyiv at a total solar radiation of 708 MJ/m^2 and the number of vehicles in the traffic junction of 300 units

By analysing the dependence in Figure 1a, we can make conclusions about the excess of the maximum permissible concentration of formaldehyde in the air above the motorway overpass or intersection during an increase in temperature and constant atmospheric conditions. So, for the Darnytsia area, raising the temperature above 20°C leads to the concentration of formaldehyde, due to the conversion of hydrocarbon emissions from road transport, six times greater than the maximum permissible concentration of 0.003 mg/m^3.

3.2. Estimation of the non-carcinogenic risk

Using this safety criterion, as a possible risk to the population according to existing standards, we are able to assess and forecast the risks of atmospheric air pollution in the given weather conditions and transport load (traffic).

Guided by recommendations (MR 2.2.12-142-2007), valid in Ukraine, the risks to public health from non-carcinogenic and carcinogenic influences of toxic substances for the Darnytsia area under the same input conditions were determined.

The dependence between ambient air temperature and non-carcinogenic risk is presented in Figure 1b. The dependence is exponential and takes into account the air temperature and the amount of total radiation from the heated surface of the intersection (or overpass).

Non-carcinogenic assessment of the quality of atmospheric air was carried out at reference concentrations. Non-carcinogenic risk is calculated on the basis of the general criterion of the hazard index, which is defined as the sum of the factors of the hazard of substances. For formaldehyde, the minimum risk of a pollutant occurs at a reference dose of 0.003 mg/m^3. Studies have shown that at an air temperature above 30°C, the non-carcinogenic risk for the health of the population is more than 10, that, according to the standard qualification of the levels of risk, is defined as significant and requires an in-depth study of the possible effects of harmful influences to solve the issue of control measures risk.

3.3. Estimation of the carcinogenic risk

Carcinogenic risk (defined as the product of the specific carcinogenic risk of formaldehyde multiplied by the average annual concentration) is within the median - acceptable for production conditions, but subject to impact on the entire population and requires dynamic monitoring and in-depth study of possible measures.

Recently, when assessing the impact of man-made streams in urban areas, the latest reconstruction and planning technologies are being replaced by the combination of “green building”. By understanding, under this term, a set of measures that are structured by the design and construction standards in order to reduce the negative impact on the environment and people with a simultaneous increase in the efficiency of the use of natural resources.

Nowadays, according to strategies in sustainable development of large cities around the world, “green building” is among the main ways of improving the situation and include the wide introduction of energy-efficient technologies, in particular, green roofs and enclosures.

These technologies are key when considering how it is possible to reduce the risk of the disease for a population that is constantly in a contaminated area and whose residence is bordered by motorway overpasses and large intersections.

4. Using “green” technologies for reducing of the risks of diseases

“Green” structures are a combination of layers of building materials with living plants. A properly selected assortment of plants improves the microclimate of the premises and recreational areas during their subsequent operation. Biomass of the “green” constructions:

- binds CO_2;
- operates as additional sound insulation;
- produces oxygen;

- moistens the air;
- the above-ground parts of the plants capture dust.

The green colour of plants has a positive effect on the human nervous system, improving the psycho-emotional state. Some plants are able to produce volatile phytoncides - volatile substances, which improve the sanitary and hygienic state of air. Due to the sanitary-hygienic aspect of phytoncide plants, “green” designs can be successfully used to improve public health. It is especially useful for the recreational zones of “green” roofs in places of dense urban development, where there are no green zones on the ground. “Green” roofs can successfully be used for aerotherapy in medical, educational, office and residential premises.

There are well-known “green” roofs constructed after the Second World War, mainly sanatoriums and pioneer camps, where they are used as tanning places (for example, sanatorium “Primore” on the Black Sea coast of the Caucasus). Terrace architecture of such buildings is dictated by the natural relief. There is an interesting garden on the roof of auxiliary premises and menagerie in the Sochi circus (architect Yu Shvartsbreim and V. Edemskii) (Gorokhov, 1991; Mashynskyi et al., 2001). The architects of St. Petersburg repeated the idea of the hanging garden of the Hermitage in a new way, using it in the architecture of the city airport, in the form of low circular flower beds of polyantha roses. The walls of the rooms near to the roof are covered with wild grapes. A small garden area on the roof serves as an additional place for rest for passengers (City, 2000; Sokol et al., 2000).

Aerotherapy is especially effective for people with respiratory diseases, functional disorders of the nervous system and cardiovascular diseases. In order to create a recreational and therapeutic zone of aerotherapy on the “green” roofs, we analyzed (Tkachenko, 2018a; Tkachenko, 2018b) the assortment of plants on “green roofs” of the intensive type from three regions of Ukraine: south-east (Donetsk), central (Kyiv), western (Lviv). In the first case, a steppe variety of planting was used, in the second - a unique variety of planting with the use of coniferous and deciduous large-sized plants and deciduous plants planted not in the soil, but in special containers. We evaluated the general condition of the plants after wintering visually on a five-point Tumanov scale (Tumanov, 1967). Observations of plant resistance to biotic and abiotic factors were carried out for 5-10 years. As a result, resistant phytoncide plants, which are recommended for the recreational and therapeutic zone of aerotherapy, were identified.

For a sharply continental climate there are: *Aster alpinus*, *Alyssum saxatilis*, *Artemisia*, *Deschampsia flexuosa*, *Euphorbia*, *Filipendula*, *Festuca*, *Gypsophila*, *Helictotrichon*, *Hypericum polyphyllus*, *Lysimachia*, *Leymus*, *Saponaria*, *Stipa*, *Salvia nutans*, *Tanacetum vulgare*.

For moderate-continental climate there are: *Ácer platanoides 'Globosum'*, *Acer rubrum*, *Acer rubrum 'Scanlon'*, *Berberis thunbergii*, *Berberis thunbergii*, *Berberis f. atropurpurea nana*, *Berberis f. red pillar*, *Chamaecyparis f. filifera aurea nana*, *Juniperus f. blue pacific*, *Juniperus procumbens nana*, *Juniperus f. old gold*, *Juniperus f. green carpet*, *Juniperus f. mint julep*, *Pinus sylvestris*, *Pinus mugo ‘Pumilio’*, *Parthenocíssus tricuspidáta*, *Parthenocissus f. Quinquefolia*, *Picea* *f. Laurin*, *Picea f. Nidiformis*, *Quercus paludosus multicaulus*, *Quercus rubra multicaulus*, *Spiraea japonica Golden Princess*, *Spiraea japonica Goldflame*, *Spiraea japonica 'Little Princess'*, *Spiraea f. golden princess*, *Spiraea f. Goldflame*, *Thuja occidentalis 'Danica'*, *Thuja occidentalis 'Smaragd'*, *Thuja occidentalis Brabant*, *Thuja f. Smaragd juniperus f. blue arrow*.

5. Possibilities of further use of the obtained results

As a continuation of the work, the carcinogenic risk should be identified for different age groups of the population, which is necessary for more reasonable decision-making in urban planning. Further development of the estimation and forecast of the photochemical smog over motorways and at the surrounding buildings is also necessary.

These studies can also be used in assessing the degree of environmental safety of the urban environment and the risk to public health. The influence of "green construction" on reducing emissions from motor vehicles in urban areas should be taken into account in developing plans and concepts of socio-economic development of the city.

Studies on the use of phytoncide plants with a high adaptive potential on "green" structures are of great importance for the prevention of a decrease in the incidence among the population. The proposed assortment of plants can be used for aerotherapy on green roofs with similar climatic conditions.

Conclusions

Recently in urban areas, there has been an increase in emissions from motor vehicles that are simultaneously located in so-called "traffic jams" on overpasses and intersections. Along with the increase of emissions from motor vehicles that work on traditional fuels, there is an increase in secondary pollution of atmospheric air from formaldehyde due to photochemical transformations. On the basis of the analysis of formaldehyde atmospheric pollution in the urban environment from the emissions of motor vehicles, the health risks of the population were calculated. Calculations have shown that in conditions of abnormal heat in a stable atmosphere the concentration of formaldehyde already exceeds the maximum permissible norm at temperature values above 20°C. At an air temperature above 30°C, the non-carcinogenic risk for the health of the population according to the standard qualification of risk levels is defined as significant and requires an in-depth study of the possible consequences of harmful effects to solve the problem of risk management measures. To reduce the risk of disease in the population, it is proposed the construction of "green" buildings - compact "green" structures using a variety of phytoncide plants that help to destroy the pathogenic microflora and improve the microclimate of residential premises.

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Oszacowanie i ograniczenie ryzyka spowodowanego zanieczyszczeniem powietrza w miastach

Streszczenie: Wzrost temperatur w lecie nasila się i powoduje wzrost zanieczyszczenia powietrza poprzez transformację fotochemiczną. Głównym źródłem zanieczyszczenia w miastach są pojazdy. Wykonano obliczenia strumienia konwekcyjnego z ciepłej powierzchni skrzyżowań i wiaduktów oraz oszacowano wtórne zanieczyszczenie formaldehydem przez transformacje fotochemiczne. W temperaturach powyżej 30°C ryzyko nierakotwórcze wynosi więcej niż 10 (znaczące) i wymaga dogłębnych badań dotyczących szkodliwości. Ryzyko rakotwórczości waha się od mediany do akceptowalnej i wymaga systematycznej kontroli i dogłębnych badań. Zmniejszenie ryzyka jest możliwe dzięki „zielonemu” projektowi: „zielone” dachy, pionowe zazielenienie, bloki elewacyjne itp. Zastosowanie roślin fitonitowych niszczy patogenną mikroflorę i poprawia mikroklimat przedwczesnych zmian. W artykule zaproponowano gatunki roślin odpowiednich do budynków medycznych i edukacyjnych w strefie klimatu kontynentalnego.

Słowa kluczowe: zanieczyszczenie atmosfery, formaldehyd, transformacja fotochemiczna, struktury „zielone”, roślina fitoncydowa