Filtering of outside air in HVAC inlet plenums in urban environment

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Abstract. An experimental inlet air strainer was presented, fitted into an outer wall of a building to filter outside air using various sorbents and chemical adsorbents. The experimental strainer was composed of the following components: an air duct, 100 mm in diameter and 400 mm long; axial fan 100 m³/h; replaceable filters, thickness of each filtering layer was 20 mm to enable replacement of sorbents and chemical adsorbent. Total 6 inlet air filtering options have been researched: 1 – filter element (activated carbon), 2 - schungite, 3 - zeolite, 4 - manganese dioxide chemisorbent with silica gel sorbent, 5 - four filters in the following order: schungite + silica gel + manganese dioxide + zeolite, 6 - activated carbon + silica gel + manganese dioxide + zeolite. Research results showed that schungite + silica gel + manganese dioxide + zeolite are the best options to filter outside air from carbon monoxide (II); its filtering efficiency was 95.35%. Hence, the studies showed that the most effective would be to use several outside air filtering stages in urban buildings.

1. Introduction
Currently, the number of buildings, fitted with plenums in outer walls of buildings to enhance air circulation in premises, is growing. In modern urban conditions with external sources of emissions this may lead to even more internal air pollution. Plenums of buildings are not capable of filtering gaseous impurities, only providing means of filtering mechanical impurities, some units are only fitted with activated carbon filter elements [1]. Besides, there has been no meticulous substantiation of the sorbent’s mass, layer thickness, it has not been established how long the sorbent’s activity lasts. In addition to that, concentrations of gaseous substances in the outside air over the entire height of the building have not been taken into account.

Thus, currently the issue of selecting a method for filtering gaseous impurities from outside air [2-4] in plenums at different heights of building facades has still not been resolved.

2. Formulation of the problem
The goal of this research is to develop and substantiate methods of filtering outside air from gaseous pollutants in urban buildings, depending on the outdoor air quality.

Research objectives: 1. Develop an experimental outside air strainer with various strainer options using sorbents (activated carbon, shungite, zeolite), as well as a chemical adsorbent (manganese dioxide). 2. Conduct on-site studies to select the best method of filtering fresh air from carbon monoxide (II) coming into buildings. 3. Generate empirical plots of dependencies of carbon monoxide (II) concentration in the inlet air from time for various strainer options.
In order to find solutions for these problems, carbon monoxide (II) was selected as a pollutant being the most persistent impurity in the air [4,5]. Carbon monoxide (II) is a conservative impurity and can only be removed from premises by HVAC [6-10]. Therefore, this research proposes methods of improving the indoor air quality in urban buildings, which can be applied in plenums of HVAC systems to remove carbon monoxide (II) CO along the entire height of facades of buildings [10-14]. An experimental strainer has been designed and mounted in the outer wall of a building to research how various sorbents, as well as chemical adsorbent, react with carbon monoxide (II) [15-20].

In order to filter carbon monoxide (II) from the air, an experimental strainer has been assembled, consisting of the following components: 1. an air duct with a diameter of 100 mm and a length of 400 mm; 2. axial fan with a capacity of 100 m$^3$/h; 3. replaceable filters with an internal diameter of 85 mm with an air intake grille, the thickness of each filtering layer is 20 mm to accommodate sorbents and chemical adsorbent. The strainer is shown in Fig.1. Six (6) inlet air strainer options were introduced to conduct researches on the experimental strainer: 1 - activated carbon filter element; 2 - shungite filter element; 3 – zeolite filter element; 4 - two filter elements: manganese dioxide chemical adsorbent and with silica gel sorbent (to eliminate formation of manganese hydroxides in case of increase of water vapor in the air); 5 - four filter elements in the following order: schungite + silica gel + manganese dioxide + zeolite; 6 - four filter elements: activated carbon + silica gel + manganese dioxide + zeolite.

Filter elements of round cross section with a sorbent layer and chemical adsorbent layer were assumed to be of equal thickness of 20 mm. The filtering surface area in all strainer options was 0.00567 m$^2$. Filter elements could be installed into the strainer both in isolation from one another, as well as one by one in a row (Figure 1).

![Figure 1. Experimental inlet air strainer: 1 – an outer wall of a building; 2 – duct; 3 – fan; 4,5,6,7 – replaceable filter elements options with various sorbents and chemical adsorbents.](image)

The strainer’s adsorbent layer is protected on both sides from mechanical impurities by means of filtering paper. The filter housing is made of heat-resistant ABS plastic.

The sorbents and chemical adsorbent being researched have the following characteristics:

- AR-B activated carbon in the form of black cylindrical granules, the particle size is primarily 2.8 mm. It has absorbing, as well as minor holding properties.
shungite is a mineral which rests somewhere between anthracite and graphite in composition and properties. It possesses sorption and catalytic properties. Karelian shungite was selected for the research - it is a natural mineral. It is unique in chemical composition and properties, in terms of the quality of the fine powder created on its basis, which had been packed into the filter element.

zeolite mined from Kholinskoe deposit in Chita region. 1-3 mm fractions were used in the experiment.

manganese oxide (IV), manganese dioxide MnO₂ is a black powder. The basic idea of the filtration method lies in a chemical reaction with carbon monoxide (II): MnO₂ + CO = MnCO₃.

silica gel to absorb water vapor, as well as adsorb some other vapors and gases.

An internal-combustion engine (190 hp) was selected as an air pollutant; air was supplied to the experimental strainer via an air duct from the exhaust pipe of a vehicle running at idle speed. During the experiment, carbon monoxide (II) concentrations were measured both outside and inside the premise; air flow rate, air temperature and humidity were recorded.

3. Solution of the problem
Based to experiment results, the average values of CO concentrations inside and outside of the premise were calculated for six various research options (Table 1).

| Option number | Sorbent / chemical adsorbent type | Inlet CO concentration, mg/m³ | Outlet CO concentration, mg/m³ | Filtering efficiency, % | Air flow rate during experiment, m³/h |
|---------------|----------------------------------|------------------------------|-------------------------------|-------------------------|-------------------------------------|
| 1             | activated carbon                 | 66.25                        | 18.75                         | 71.69                   | 79.2                                |
| 2             | shungite                         | 61.11                        | 8.22                          | 86.55                   | 78.76                               |
| 3             | zeolite                          | 67.14                        | 19                            | 71.702                  | 79.9                                |
| 4             | Silica gel + MnO₂                | 85                           | 13.68                         | 83.90                   | 79.75                               |
| 5             | shungite silica gel + Mo2 + zeolite | 86                           | 4                            | 95.35                   | 72.56                               |
| 6             | activated carbon + silica gel + MnO₂ + zeolite | 85                           | 25.57                         | 69.92                   | 73.48                               |

Experiment results showed that the fifth strainer option (shungite + silica gel + MnO₂ + zeolite) (Table 1) proved to be the most efficient sorbent coupled with chemical adsorbent capable of filtering out carbon monoxide (II) in the experimental strainer, showing filtering efficiency of 95.35%; the second best strainer option was shungite - 86.55%; CO filtering efficiency of the fourth strainer option (silica gel + manganese dioxide) was 83.90%; the filtering efficiency of the first strainer option (coal) was 71.698%, the filtering efficiency of the third strainer option (zeolite) was 71.70%. The sixth strainer option (activated carbon + silica gel + manganese dioxide + zeolite) had lowest efficiency in terms of filtering out carbon monoxide (II) - 69.92%. The research also included measurements of CO concentrations for all strainer options with time. Based on measurement results empirical plots of each option were generated (Figure 2).
Figure 2. Empirical plots of CO concentrations versus time of filtration for various strainer options:
1 – option one (activated coal); 2 – option two (shuntite); 3 – option three (zeolite); 4 – option four (MnO₂ + silica gel); 5 – option five (shuntite + manganese dioxide + silica gel + zeolite); 6 – option six (coal + manganese dioxide + silica gel + zeolite).

From Figure 2 it can be seen that, despite high filtering efficiency of manganese dioxide 83.9%, the CO concentrations at the outlet of filtering unit increase sharply over a period of 2 hours, while option number four (silica gel + manganese dioxide) becomes ineffective with CO concentrations at the inlet of experimental strainer exceeding the norm just after 2 hours (5 mg / m³).

In case of option three (zeolite), the output CO concentration exceeds the norm in half a day (10 hours).

Test results of option number two (filtering element packed with shungite from Karelian deposit) show that the CO concentration at the output of the experiment strainer exceeds the norm after 54 hours, that is, 2.5 days; research results of option number one (activated carbon) show that CO concentration exceeds the norm after one day (27 hours).

In case when option number five is used for filtering outside air (schungite + silica gel + manganese dioxide + zeolite) the CO concentration at the output of the strainer will exceed the norm only after 8 days (192 hours). The filtering efficiency of this option is the highest – 95.35%, whereas in case of using the research option number six (activated carbon + silica gel + manganese dioxide + zeolite) the concentration will exceed the norm in a day (20 hours).

4. Summary

1. On-site studies have been carried out which allowed to collect data on selection of air filtering method capable to filter carbon monoxide (II) in an experimental strainer installed in an outer wall of a city building, as exemplified by the city of Tyumen.

2. The research results obtained using the experimental strainer showed that the most effective method of filtering carbon monoxide (II) from the outside air is by using: schungite + silica gel + manganese dioxide + zeolite; the inlet air filtering efficiency of the method was 95.35%.
3. Empirical plots of CO concentrations depending on time have been generated for various inlet air strainer options. With the most efficient research method of air filtering (shungite + silica gel + manganese dioxide + zeolite) the CO concentration indoors will exceed the norm after 8 days.

4. The presented research results can be used to select and substantiate outside air filtering method to be applied in HVAC systems, in particular, in the inlet plenums of buildings in the urban environment with high air pollution generated by motor vehicles.

References

[1] Kazakevich M I 2007 Current problems of buildings and aerodynamics Works of young scientists: abstracts of reports 1 152–161
[2] Kasimov N S 1990 Environmental and geochemical assessments of cities Conference Series: Moscow State University Bulletin 3 5–12
[3] Kvashnin I M 2007 Dispersion and establishment of emission standards for an enterprise AVOK 8 20–22
[4] Kitaitseva E Kh 1999 Natural ventilation of residential buildings AVOK 3 14–17
[5] Kononovich Yu V 1999 Fundamentals of environmental design in urban planning (Moscow: Izdatpress) p 125
[6] Korolev A A 2003 Medical ecology (Moscow: Academy Publishing Center) p 192
[7] Riabov S N 2005 Development of the characteristics of an integrated assessment of the environmental safety of air of residential premises and measures ensuring it (Volgograd: Civil Engineering Institute) p 200
[8] Kuznetsov I S 2007 Modeling of harmful substances concentration fields and substantiation of air exchange in industrial premises (Voronezh: Civil Engineering Institute ) p 125
[9] Kuzmichev A V 2005 Fundamentals of air basin monitoring heavily built up areas with decentralized heat supply systems (Volgograd: Volgograd Polytechnic University) p 129
[10] Kulikov V G 1998 Comparative hygienic assessment of indoor environments of residential buildings located in residential areas with different levels of air pollution Occupational medicine and human ecology in the mining and metallurgical industry: collection of scientific works 1 119–125
[11] Kuchma V R 1994 Epidemiology of diseases in population living in environmentally unfriendly territories Environment safety of regions and market relations: International conference materials 1 363–368
[12] Lebedkova S E 1991 Prevalence of cardiovascular diseases in children of school age, with due regard to the ecological situation of the ambient air Pediatrics 12 41–44
[13] Livchuk V I 1999 Solutions for the ventilation of multi-storey residential buildings AVOK 6 21–25
[14] Livchuk I F 2005 Ventilation in high-rise residential buildings (Moscow: ABOK – PRESS) p 136
[15] Livchuk I F 1951 Ventilation of multi-storey residential buildings (Moscow: State publishing house of architecture and town planning) p 140
[16] Litvinova N A 2010 Motor transport and air purity in residential premises A collection of materials of the IIIrd International Applied Science Conference 1 113–116
[17] Malakhov P V 2003 Design of a natural and mechanical ventilation system of a residential building in Moscow AVOK 3 12–17
[18] Osipova E O 2003 Development of a filtering sorbing material for carbon monoxide toxicity elimination Young scientist 1 85–87
[19] Masterov I V 2005 Ventilation (St. Petersburg: Dilya Publishing House) p 192
[20] Litvinova N A 2019 Ventilation and air quality in urban buildings (Moscow: Infra-M) p 170