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Research article

CHEMICAL AIR POLLUTION IN RESIDENTIAL PREMISES AS A HEALTH RISK FACTOR

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Up-to-date techniques applied in physical-chemical studies made it possible to identify and quantify chemical pollutants in the air inside contemporary residential premises in a large megacity and then create a database on them. This database has a list of more than 600 chemicals from 18 groups of volatile hydrocarbons and covers hygienic standards for their contents, their hazard category, and ranges of detected concentrations. Major sources of air pollution with these chemicals in residential premises were also identified. From the hygienic point of view, a significant fact is that there are no hygienic standards for more than 60 % of chemicals detected in air in residential premises. Formaldehyde, phenol, and styrene are priority chemicals for quality monitoring and risk-based control of hazards posed by chemical air pollution both in newly built houses that are at the approval stage and already exploited ones. Formaldehyde, benzene, phenol, styrene, acetophenone, ethylbenzene, hexanal, nonanal, butyl acetate, ethyl acetate, isopropanol, and trimethylbenzene are the most hygienically significant volatile organic compounds for quality control and health risk assessment considering frequency of their occurrence, concentration levels, concentrations exceeding MPC, group affiliation, hazard category, and ability to transform. When controlling natural chemicals that occur in air in residential premises due to some internal pollution sources, we should bear in mind that transformation may result in a new structure of pollution and new occurring chemicals can be more toxic and hazardous than original ones.

To minimize risks associated with exposure to chemical pollution and to assess chemical safety of air in residential premises, we recommend wider use of up-to-date physical and chemical methods for qualitative and quantitative analysis thereby securing identification of a wide range of pollutants including potentially hazardous ones. Since certain chemicals have been detected for which no safety criteria have been developed so far, it is especially vital to perform research in the sphere of hygienic standardization and to develop methodical documents aimed at providing adequate hygienic assessment of quality and chemical safety of internal environment in residential premises.

Keywords: *residential premises, air, chemical pollution, chromatography-mass spectrometric studies, environmental health risks.*

At present, the residential real estate market is developing quite actively in many regions throughout the country. Any type of housing, be it an individual low-rise house, an apartment or a room in a high-rise building, is not only a construction object but primarily an environment where people spend most of their lives. Given that, issues related to quality and hygienic safety of this environment are quite topical and significant [1–5].

A pressing issue the hygienic science has to resolve now is establishing regularities in how the environment in residential premises becomes qualitative and safe [6–8]. Chemical air pollution in residential premises is among the most significant risk factors for public health due to several reasons. Chemicals can be emitted into air simultaneously from several internal sources and air exchange in small rooms is rather weak and insufficient to attenuate pollution; chemicals persist in residential premises for a long time and chemical structure of this pollution is stable, and this gives certain priority to air in residential premises over other environments. Therefore, many experts believe residential premises to make a major contribu-

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tion to the total chemical burden on people associated with air pollution[1] [9–12].

Undoubtedly, ambient air is an external source of air pollution in residential premises. High levels of ambient air pollution can exert their influence on growing incidence of respiratory diseases, diseases of the central nervous system, cardiovascular system, blood system, and oncological pathologies [13–17]. Previous studies, both ours and accomplished by other experts, revealed more than 10 various internal sources of air pollution in residential premises, apart from ambient air as an external source. Primarily, these sources are construction and finishing materials made of polymer and polymer-containing components. House dust is another significant source of pollution since non-organic and organic chemicals are sorbed on its particles. These chemicals include street dust, particles of pets' skin and fur, particles of pets' food etc. Air pollution in residential premises can partially occur due to improper functioning of ventilation, sewage, and rubbish chutes; natural gas combustion contributes to it. Household washing powders, cleaners, polishes, glues, varnishes, paints, perfumes, cosmetics etc. also make a certain contribution. Results obtained by multiple studies confirm that indoor chemical air pollution is by 1.5–4.0 times higher than outdoor air pollution on the same territory [18–20].

There are so called "phenol buildings" described in literature; 50 years ago, the World Health Organization introduced a specific term "Sick Building Syndrome". This term comprises various health disorders that develop in people who have just moved into new residential buildings. These health disorders often become apparent through lower working capacity, variable allergic reactions, rapid fatigability, frequent headaches etc. [19–22]. "Sick Building Syndrome" probably occurs due to chemical air pollution inside buildings and, first of all, such pollutants as volatile organic compounds. Higher air tightness is considered the principal cause of "Sick Building Syndrome" since it reduces outdoor air supply; another important cause is more intense use of polymer and synthetic materials in construction as well as in decorating and furnishing. Some studies describe results obtained by profound biomedical examinations of people who live under long-term exposure to formaldehyde pollution inside their residential premises and provide substantiation for authentic mathematical models of a relationship between people's health and exposure to this chemical in the living environment [23].

Negative influence exerted by chemicals on human health is an indisputable fact and the necessity to search for sources of air pollution in residential premises and to examine than is just as obvious. Our present study concentrates exactly on this matter.

The research goal was to identify and quantify the maximum possible range of organic compounds that pollute air in residential premises; to reveal their sources; to determine the list of the most hygienically significant chemicals in order to minimize health risks and accomplish risk-based control over safety of the environment in residential premises.

Materials and methods. Air inside contemporary residential buildings was selected as a research object. We examined air inside 207 apartments located in high-rise apartment blocks, both typical and individually designed. We also examined air inside low-rise cottages and townhouses. The research design made it possible to obtain qualitative and quantitative description of chemical air pollution in different types of residential buildings in a large megacity.

Air samples for chemical analysis were taken in the center of a living room with all the windows closed and air conditioning switched off. Prior to air sampling, apartments had not been ventilated for 12 hours.

Volatile organic compounds were identified and quantified in air in residential premises by using chromato-mass-spectrometry. The sensitivity of the method is at the same level or below than the existing hygienic standards for contents of organic compounds

[1] Novikov S.M. Khimicheskoe zagryaznenie okruzhayushchei sredy: osnovy otsenki riska dlya zdorov'ya naseleniya [Chemical pollution of the environment: basic of health risk assessment]. Moscow, 2002, 24 p. (in Russian).

C_1–C_{20} in air with unidentified chemical pollution. The analysis was performed on a chromato-mass-spectrometry system manufactured by Thermo Fisher Scientific (USA) that included Focus GC gas chromatographer (USA) with electronic gas flow control, DSQ II mass spectrometric detector with quadrupole mass analyzer (a range of measured atomic mass numbers is from 1 to 1050), as well as ACEM 9300 thermal desorber with gas sample cryofocusing. We applied specific software package to collect and store mass spectra, to analyze measurement results, and to perform quantitative analysis. All the obtained results were compared with data taken from the NIST 08 Mass Spectral Library (more than 220 thousand spectra for more than 190 thousand chemical compounds).

Air samples were taken into sorption tubes on a polymer sorbent (Tenax TA, the granulation is 0.20–0.25 mm, the specific surface area is 35 m^2/g) with following thermal desorption. The results were statistically analyzed in Microsoft Excel. This article dwells on the averaged results of analytical replications. Data error does not exceed its allowable level ($M \leq 5$ %).

Formaldehyde was identified in air in residential premises by using our own high performance liquid chromatography (HP-LC) method in accordance with the methodical guidelines[2].

Heavy metals in their aerosol form were identified in air in residential premises by using a Beckman atomic-absorption spectrophotometer equipped with Massmann Cuvette and graphite tubes.

To assess hazards, the identified concentrations of chemicals were compared with average annual and average daily maximum permissible concentrations (MPC) established for ambient air in settlements. In case no such MPC were established for a specific chemical, we took maximum single MPC and tentatively safe exposure levels (TSEL)[3].

Results. Air inside each analyzed residential premises had a wide range of chemicals, namely, approximately 600 volatile organic compounds. Their qualitative and quantitative structure depended on purposes of a specific room and characteristics of internal pollution sources.

Air quality in enclosed spaces was established to depend on ambient air pollution regarding certain chemicals. Thus, concentrations of nitrogen oxides, carbon oxide and dust inside residential buildings corresponded to their concentrations in outdoor air, excluding situations when internal pollution sources were also present.

Lead, sulfur dioxide and ozone were identified in air in residential premises mostly in concentrations lower than in ambient air outdoors.

Overall, we identified 609 chemicals from 18 groups of volatile organic compounds in air in residential premises. Table 1 provides data on basic groups of volatile organic compounds identified in analyzed air and their major sources.

Concentrations of volatile organic compounds were higher in practically all samples taken in residential premises than in those taken outside. Contents of toluene, xylene, benzene, acetaldehyde, methyl ethyl benzene, propyl benzene, ethanol, ethyl acetate, acetone, phenol, and some saturated hydrocarbons (in particular, pentane, hexane, octane, and nonane) were higher inside buildings than in ambient air, the difference reaching 10 times or even higher.

Figure 1 shows typical group structure of organic compounds in air in residential premises as per their number in each group. Saturated, unsaturated, aromatic and cyclic hydro-

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[2] MUK 4.1.1045-01. VEZhKh opredelenie formal'degida i predel'nykh al'degidov (S2–S10) v vozdukhe (utv. Glavnym gosudarstvennym sanitarnym vrachom Rossiiskoi Federatsii Pervym zamestitelem Ministra zdravookhraneniya Rossiiskoi Federatsii G.G. Onishchenko 5 iyunya 2001 g.) [The Methodical Guidelines MUK 4.1.1045-01. HP-LC to identify formaldehyde and saturated aldehydes (C_2–C_{10}) in air (approved by G.G. Onishchenko, the RF Chief Sanitary Inspector, the First Deputy to the RF Public Healthcare Ministry on June 5, 2001)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200029341 (May 17, 2022) (in Russian).

[3] SanPiN 1.2.3685-21. Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya (utv. postanovleniem Glavnogo gosudarstvennogo sanitarnogo vracha Rossiiskoi Federatsii ot 28 yanvarya 2021 goda № 2) [Sanitary Rules and Standards 1.2.3685-21. Hygienic standards and requirements to providing safety and (or) harmlessness of environmental factors for people (approved by the Order of the RF Chief Sanitary Inspector issued on January 28, 2021 No. 2)]. *KODEKS: electronic fund for legal and reference documentation.* Available at: https://docs.cntd.ru/document/573500115 (May 17, 2022) (in Russian).

Table 1

Groups of volatile organic compounds and sources of their entry into air in residential premises

Groups of compounds		The number of identified compounds	A share of compound for which hygienic standards are established, %	Ranges of identified concentrations, mg/m^3	Sources*	Hazard categories
Saturated hydrocarbons	Normal	19	56	0.05–2.52	1–7	4
	Branched	34	0	0.004–4.15	1–5, 7	–
Unsaturated hydrocarbons		65	18	0.001–0.938	1–3, 5, 6	3–4
Aromatic hydrocarbons		63	43	0.001–1.524	1–7	2–4
Cyclic hydrocarbons		45	15	0.008–0.52	1, 3, 5	–
Simple and complex ethers		55	54	0.001–0.786	1, 5, 7, 9	3–4
Ketones		49	13	0.002–4.05	1–5, 9, 11	3–4
Aldehydes (saturated and unsaturated)		43	41	0.004–0.558	1–6, 9, 11	2–4
Alcohols		42	49	0.005–1.12	1, 4, 5, 7, 9	3–4
Terpenes		29	17	0.002–0.790	3, 4, 7–9	–
Organic acids		17	58	0.001–0.958	2, 5, 9, 11	2, 3
Furans		17	20	0.012–0.552	1–4, 9	–
Indane compounds		15	0	0.004–0.23	2, 3, 5–7	–
Phenols		7	40	0.001–0.323	1, 2, 5	2
Oxygen-containing compounds		7	0	0.035–0.045	5, 7	–
Nitrogen-containing compounds		48	23	0.001–0.421	3–6, 11	2–4
Halogen-containing compounds		29	54	0.011–1.400	1, 3–5, 7, 10	2–4
Sulfur-containing compounds		25	40	0.005–0.365	1, 2, 4, 5, 9	1–4

Note: *Major sources that create chemical pollution in air in residential premises include: **1** – construction and finishing materials; **2** –polluted ambient air; **3** – tobacco smoke; **4** – house dust; **5** – anthropogenic toxins and pets' vital activity products; **6** – products of incomplete gas combustion; **7** – household chemicals including washing powders, polishes for furniture and floor, glues for floor boards, varnishes and paints, aerosol air fresheners; **8** – perfumes and cosmetics, flowers and plants; **9** – cooking; **10** – tap water usage (showering, drinking, laundry, boiling, doing the dishes, cleaning etc.); **11** – products created by transformation of pollutants.

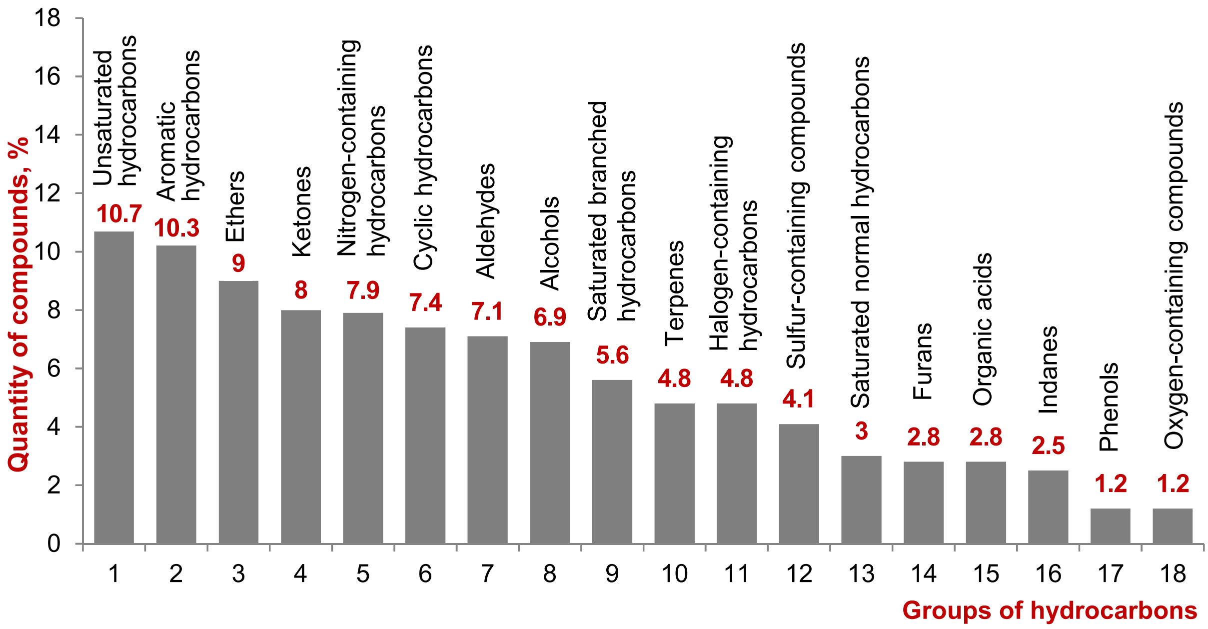

Figure 1. Group structure of organic compounds in air in residential premises distributed as per group shares (determined as per a number of compounds in each group)

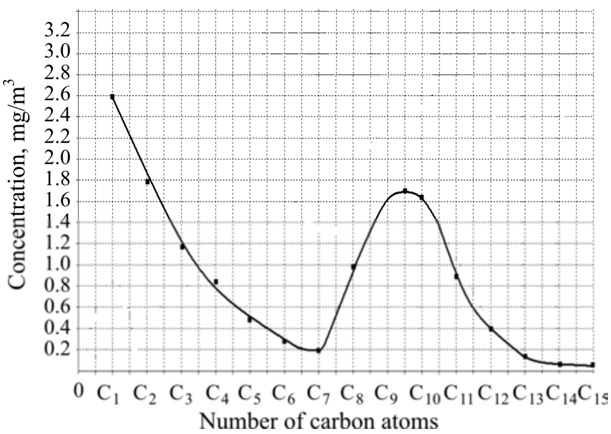

Figure 2. Contents of saturated hydrocarbons in air inside apartments depending on the number of carbon atoms in their chemical formula

carbons accounted for 44 % of the total quantity of volatile organic compounds. Saturated and aromatic hydrocarbons accounted for more than one third (34 %). Variable functional groups also had significant shares in the structure of compounds in air in residential premises; in particular, this concerns oxygen-, nitrogen-, sulfur-, and halogen-containing compounds.

Hydrocarbon contents went down from the simplest representative C_1 (methane) to C_7 (heptane), then increased reaching its peak for C_9 (nonane) and then went down again (Figure 2).

The established trend is in line with distribution of normal saturated hydrocarbons in ambient air in industrial areas with low pollution levels. An increase in contents of hydrocarbons C_8–C_{12} might be due to their migration into air from construction and finishing materials and household chemicals.

It seemed rather difficult to assess hazards posed by a wide range of organic compounds occurring in air in residential premises since there were no existing hygienic standards for a significant number of them.

As for compounds with established safety levels of their concentrations, their total contents could hardly be considered hazardous since they occurred in concentrations not exceeding MPC. Most such compounds belonged to the fourth hazard category regarding their toxicological properties.

Special attention was given to chemicals from aromatic hydrocarbons group. Benzene, toluene, ethylbenzene, xylenes, propyl benzene, methyl ethyl benzenes, and trimethylbenzene occurred practically in all analyzed residential premises. They belong to the group of the most hazardous chemicals out of those identified in air given their hygienic significance and ability to transform by oxidation thereby generating products that are more toxic [18]. Some aromatic hydrocarbons occurred in concentrations that were significantly higher than average daily MPC. Thus, if an apartment was just after repairing and had new furniture, or a room was polluted with tobacco smoke, benzene concentration reached 15 average daily MPC; ethylbenzene, 8 average daily MPC; trimethylbenzene, 8 average daily MPC; etc. (Table 2).

This indicates it is necessary to control these compounds in air in residential premises.

We detected a trend for aromatic hydrocarbons, similar to saturated ones, to distribute

Table 2

Aromatic hydrocarbons identified in air in residential premises and their hygienic significance

Compound	The number of carbon atoms in the molecule	Ranges of concentrations, mg/m^3	Concentrations exceeding average daily MPC, maximum number of times
Benzene	C_6	0.006–1.524	15.2
Toluene	C_7	0.001–0.963	1.6
Ethylbenzene	C_8	0.001–0.854	43.0
Xylenes	C_8	0.004–0.792	4.0
Methyl ethyl benzene	C_9	0.002–0.602	20.1
Trimethylbenzene	C_9	0.002–0.520	34.7
Methyl isopropyl benzene	C_{10}	0.002–0.125	8.9
Naphthalene	C_{10}	0.0–0.150	21.4
Styrene	C_8	0.001–0.135	68.0
Diethylbenzene	C_{10}	0.002–0.077	15.4
Tetramethylbenzene	C_{10}	0.003–0.280	28.0

depending on their molecular structure. Their contents were shown to go down as the number of carbon atoms in their formula grew and the simpler hydrocarbons occurred in larger quantities than their high-molecular homologs.

Aldehydes were the most hygienically significant compounds among oxygen-containing ones. We identified a wide range of saturated normal aldehydes (from formaldehyde to dodecanal) and their isomers as well as unsaturated (acrolein, methyl acrolein) and aromatic aldehydes (benzaldehyde, 4-methylbenzaldehyde); in some cases their concentrations exceeded maximum permissible ones.

Hexanal, formaldehyde, acetaldehyde, and nonanal were the most hygienically significant aldehydes. These compounds can be found in various solvents, construction and finishing materials, household chemicals, perfumes, and some other substances that are commonly stored and used in residential premises.

Formaldehyde and hexanal were identified in air inside practically all the examined rooms. Formaldehyde occurred in concentrations from 0.001 mg/m^3 (in ecologically clean apartments) to 0.170 mg/m^3 (in apartments with new furniture made of wood chipboards). Hexanal was identified within the range of concentrations 0.001–0.08 mg/m^3. We should note that the aforementioned aldehydes occur in air not only due to migration from variable internal sources but also due to transformation of other organic compounds.

When it comes down to ketones, acetophenone, acetone and methyl ethyl ketone (butanone) are the most significant ones given their prevalence, total contents, the number of representatives and concentrations. Acetone concentration reached 5.6 average daily MPC in some places (in particular, close to where household chemicals were stored). Acetophenone concentrations (comes from perfumes and cosmetics) reached nine average daily MPC.

Some ketones do not have hygienic standards established for them. Among such compounds, 2-heptanone, 2-butanone, 2-octanone, and 2-hexanone occurred frequently and in the highest concentrations.

As for alcohols, 2-pentanol, n-butanol, isobutanol, 2-butanol, 1,4-dioxane, diphenyl ether, ethyl- and butyl acetates were the most hygienically significant. Alcohols occur in air in residential premises from such sources as people and pets' vital activity products, cooking, household chemicals, plants, and perfumes.

Furans also should be given similar attention among other oxygen-containing compounds. They are contained in tobacco smoke, motor transport exhausts, gas combustion products, etc. Furan, 2- and 4-mehtylfuran have high hygienic significance. Furan was identified in concentrations reaching eight MPC in rooms that were heavily polluted with tobacco smoke. Some compounds from the furan group do not have hygienic standards established for them. Among such compounds, 2-pentyl- and 2-butyltetrahydrofuran were identified in the highest concentrations.

Nitriles and nitrogen-containing compounds is another group of chemicals with certain hygienic significance. Nitrogen-containing compounds are applied as plasticizers and modifiers when colorants and finishing polymer materials are manufactured. Nitrogen-containing compounds occur in air due to tobacco smoking or they can sorb on house dust; apart from that, nitriles and nitrogen-containing compounds can also be final products resulting from transformation. Since their reaction abilities are rather weak, we can expect these compounds, just like ketones, to accumulate in air in enclosed spaces, which means their contents should be controlled. However, hygienic standards are established for only 23 % of the all nitrogen-containing compounds identified in air in residential premises.

We should emphasize that it was extremely difficult to assess hazards posed by the whole range of identified chemicals since there were no established hygienic standards for a significant part of them. Hygienic standards are available only for 31 % of the identified chemicals. Hygienic standards exist for only 20 % of all the identified toxic furans; cyclic hydrocarbons, 15 %; aldehydes, 41 %; phenols, 40 %; alcohols, 49 %; sulfur-containing compounds, 40 %; halogen-containing compounds, 54 % (Table 1). Meanwhile, these compounds penetrate air in residential premises from polymer materials or with tobacco smoke, due to tap water consumption or as final products when basic pollutants transform. Given their extremely weak reaction abilities and ability to transform, these compounds can accumulate in air in residential premises in significant amounts.

It seemed very important to identify major sources of various chemicals. Table 3 provides the list of 10 major sources that create air pollution in residential premises as well as summarized results obtained by examining spectra of variable compounds that come from these sources into air in residential premises.

We estimated pollution levels as per the total MPC excess (K_{total}) and obtained the following results. K_{total} determined for volatile organic compounds reached 79 for air inside rooms that were heavily polluted with tobacco smoke; 70, for a room with new linoleum on the floor. We calculated several values for rooms in a comfortable apartment after it has been repaired using all the advanced technologies and materials: bedrooms, up to 42; rooms without any furniture, up to 30; living rooms, 17; children's rooms, up to 20. For reference, K_{total} calculated inside cottages located in the countryside was often lower than 5 and never exceeded 10.

Table 4 provides the list of compounds with their concentrations exceeding hygienic standards in more than 10 % of the analyzed apartments.

Formaldehyde, phenol, and styrene are obviously the most widely spread chemical pollutants occurring in air in residential premises.

Formaldehyde migrates into air in residential premises from furniture made of wood chipboards and the process may persist for many years. Besides, formaldehyde can be found in heat insulating materials, linoleums,

Table 3

Quantitative assessment of volatile organic compounds entering air in residential premises from major internal sources of pollution

Internal sources of pollution	The number of compounds	The number of groups	The share of compounds without any hygienic standards established for them, %
Construction and finishing materials	154	13	39
Vital activity products	157	18	59
Tobacco smoke	121	18	72
Cases of household appliances	33	8	48
Household chemicals	83	12	34
Products of natural gas combustion and cooking	67	13	67
Perfumes and cosmetics	58	10	45
House dust	80	13	63

Table 4

Chemicals identified in air in residential premises in concentrations higher than hygienic standards

Chemical	A share of samples with concentrations higher than MPC, %	MPC exceeded by (times)
Styrene	35	1.5–18.0
Formaldehyde	32	1.2–17.0
Phenol	20	1.0–5.0
Hexanal	17	1.2–6.5
Nonanal	15	1.2–4.5
Ethylbenzene	14	1.8–8.2
Butyl acetate	10	1.0–2.2
Ethyl acetate	10	1.0–3.2
Isopropanol	15	1.0–2.5
Benzene	12	1.2–5.0
Acrolein	10	1.0–7.0
Octanal	11	1.2–2.5
Dichlorobenzene	10	1.3–3.3
Trimethylbenzene	15	1.3–3.3
Acetophenone	10	1.0–9.5

cosmetics, household chemicals, and shrink-proofing agents used to manufacture up-to-date textiles etc. This chemical produces general toxic, irritating and allergenic effects. It is noteworthy that formaldehyde is not only capable to directly induce allergy but also stimulate allergic reactions to other allergens.

Several research works provide data on a relationship between formaldehyde contents in air and abundance of polymer materials (the correlation coefficient equals 0.67) [18, 19]. The highest formaldehyde concentrations (0.062–0.077 mg/m^3) were detected in rooms with new furniture made of wood chipboards. Natural gas combustion is also a source of this chemical. It was established that if a 4-burner gas cooker was working for one hour, this resulted in 1.5–2.0 times increase in formaldehyde concentration in air inside a kitchen. Tobacco smoke is another source of formaldehyde. Smoke from just one cigarette was established to contain 0.035 mg/m^3 of formaldehyde. After three cigarettes have been smoked, formaldehyde concentrations in air on average grow by 42 %.

Phenol is another most widely spread and hazardous pollutant that occurs in air in residential premises. Phenol mostly comes into air in residential premises from construction materials that contain phenol-formaldehyde components (plastic coverings, certain polishers and varnishes for parquet, wood chipboards, fiberboards, plywood); paints and solvents used as protective coatings for wood; insulation materials based on foam carbamide resins; disinfectants.

Formaldehyde and phenol concentrations may largely occur in air in residential premises due to polluted ambient air since they can easily be found in industrial emissions and exhaust gases.

Styrene can also be considered a most widely spread pollutant in air in residential premises. Styrene concentrations, either equal to MPC or higher, were detected in most analyzed residential premises. Styrene comes into indoor air mostly from heat insulating and finishing materials, PC cases and cases of other electronic appliances that are made from polystyrene or polystyrene-based materials, as well as plastic coatings on kitchen furniture.

Discussion. We identified 609 compounds from 18 groups of volatile hydrocarbons in air in residential premises. Aromatic hydrocarbons and aldehydes with styrene and formaldehyde as their main representatives should be considered priority compounds for chemical-analytical control as per their contents in air, the number of identified chemicals from the group and hygienic significance. Phenol pollution in air in residential premises is another risk factor for public health.

Formaldehyde, phenol, and styrene are major indicators applied within monitoring activities aimed at assessing quality and performing risk-based control of hazards posed by chemical air pollution both in newly built residential houses that are at the approval stage and already exploited ones. These compounds, which are able to produce not only general toxic effects on human health but also allergenic (formaldehyde) and carcinogenic effects, were identified in air in most analyzed residential premises. Their concentrations exceeded MPC established by hygienic standards more frequently than concentrations of other pollutants and multiplicity of this excess was also higher (Table 5). Besides, several sources of these compounds were often found in apartments at the same time. We should bear in mind that these chemicals could be released into air from each construction material or any other source in permissible concentrations whereas the total concentration that occurs in air from different sources could well be significantly higher than the maximum permissible one as it was shown when considering formaldehyde [23]. Given that, we recommend performing mandatory control over formaldehyde, phenol, and styrene concentrations both when a new residential building or a repaired one is being commissioned and when people complain about an unsatisfactory low-quality environment. This mandatory control should also be included into risk-based surveillance over safety of the environment in residential premises.

Apart from formaldehyde, styrene, and phenol, the most hygienically significant compounds are acetophenone, ethylbenzene, hexanal, nonanal, butyl acetate, ethyl acetate, isopropanol, benzene, and trimethylbenzene (Table 5).

Contents of these chemicals should primarily be controlled in order to perform proper assessment of hygienic safety inside contemporary residential premises with unknown pollution sources; this control is also necessary when people complain about some alien smells inside their apartments or worsening health due to living there as well as when calculating risks associated with effects produced on health by volatile organic compounds occurring in the living environment.

Therefore, the results of this study as well as earlier ones made it possible to identify the maximum widest range of chemical pollutants in air in residential premises; to quantify them and to determine the actual structure of air pollution; to establish major sources of chemical pollutants in air in residential premises. We determined quantitative parameters of chemical air pollution depending on ambient air pollution, abundance of polymer materials in a given room, a number of people in a given room, a period during which a given building was exploited, air temperature and humidity, and air exchange intensity [6, 9, 19].

However, several issues have remained unresolved by now and this makes it impossible to accomplish proper sanitary-epidemiological control of chemical air pollution in residential premises supported by a relevant methodical base.

The most significant problem is lacking methodical and regulatory support for assessing hazards or safety in case the identified chemicals occur in air. In particular, it is rather unclear what a period any hygienic standards should be averaged over when we use them as reference ones within sanitary-epidemiological surveillance of chemical air pollution in residential premises, namely, average annual, average daily, or single maximum ones. Thus, there was an item in this formerly valid document[4] pointing out that chemical concentrations in air in residential premises should not exceed average daily MPC established for air in settlements when a building is being commissioned. In case there are no such MPC established for a given chemical, its concentration should not exceed maximum single MPC or TSEL. Still, there is no such requirement in recently developed documents that are valid now.

There is another important issue. How many samples should be taken, where they should be taken and what sampling conditions are proper? If we want to obtain adequate results, we need unified methodical requirements to sampling points, a number of samples, and sampling conditions and we should determine under what conditions results of one-time sampling in residential premises can be compared with average daily MPC.

Table 5

Basic hygienically significant chemical pollutants in air in residential premises

Chemical	Hazard category	Frequency, %	MPC exceeded by (times)	Major pollution sources
Styrene	2	80	1.5–18.0	Construction and finishing materials, toys, household appliances
Formaldehyde	2	100	1.2–17.0	Furniture, construction and finishing materials
Phenol	2	70	up to 4.2	Construction and finishing materials, disinfectants
Acetophenone	3	50	1.0–4.0	Furniture, resins, perfumes
Ethylbenzene	3	80	up to 3.0	Ambient air, construction and finishing materials
Benzene	2	78	1.0–6.9	Varnishes, paints, natural gas, ambient air
Hexanal	3	64	1.0–5.4	Furniture, varnishes, paints, construction materials, perfumes
Nonanal	3	60	1.0–5.4	Furniture, varnishes, paints, construction materials, perfumes
Isopropanol	3	50	up to 2.0	Household chemicals, varnishes, paints
Trimethylbenzene	3	74	1.3–3.3	Polymer construction and finishing materials
Butyl acetate	3	54	1.0–2.2	Polymer construction and finishing materials, varnishes, paints
Ethyl acetate	3	48	1.0–3.2	Polymer construction and finishing materials, varnishes, paints

[4] SanPiN 2.1.2.2645-10. Sanitarno-epidemiologicheskie trebovaniya k usloviyam prozhivaniya v zhilykh zdaniyakh i pomeshcheniyakh (utv. postanovleniem Glavnogo gosudarstvennogo sanitarnogo vracha Rossiiskoi Federatsii ot 10 iyunya 2010 goda № 64) [Sanitary Rules and Standards 2.1.2.2645-10. Sanitary-epidemiological requirements to living conditions in residential buildings and residential premises (approved by the Order of the RF Chief sanitary Inspector on June 10, 2010 No. 64)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/573500115 (May 17, 2022) (in Russian).

In addition, it is necessary to substantiate a list of procedures for chemical tests. These procedures, along with being cost-effective and available, should be highly sensitive since this gives an opportunity to ensure that test results are comparable with hygienic standards.

Therefore, adequate hygienic assessment of air quality and chemical safety under exposure to chemical pollution in residential premises requires further development of regulatory and methodical documents aiming to improve sanitary-epidemiological examinations with their focus on air.

Conclusion. We applied up-to-date physical and chemical research techniques and this allowed us to identify and quantify chemical pollutants in air inside contemporary residential premises and to create a database on chemical pollution in a large megacity. The database contains data on more than 600 chemicals from 18 different groups of volatile hydrocarbons stating their hygienic standards, a hazard category, and ranges of detected concentrations. In addition, we identified major sources of air pollution with these chemicals. It is noteworthy that there are no established hygienic standards for more than 60 % of all the chemicals identified in air in residential premises.

Formaldehyde, phenol, and styrene are priority chemicals for quality monitoring and risk-based control of hazards posed by chemical air pollution both in newly built houses that are at the approval stage and already exploited ones.

Apart from formaldehyde, styrene, and phenol, such compounds as acetophenone, ethylbenzene, hexanal, nonanal, butyl acetate, ethyl acetate, isopropanol, benzene, and trimethylbenzene are the most hygienically significant volatile organic ones for quality control and health risk assessment considering frequency of their occurrence, concentration levels, concentrations exceeding MPC, group affiliation, hazard category, and ability to transform.

When controlling natural chemicals that occur in air in residential premises due to some internal pollution sources, we should bear in mind that transformation might result in a new structure of pollution that includes new occurring chemicals, for example, aldehydes or ketones that can be more toxic and hazardous than original ones.

To minimize risks associated with exposure to chemical pollution and to assess chemical safety of air in residential premises, we recommend wider use of up-to-date physical and chemical analysis methods for identification of a wide range of pollutants. It is especially vital to develop hygienic standardization in order to minimize environmental risks and to develop methodical documents aimed at providing adequate hygienic assessment of quality and chemical safety of internal environment in residential premises.

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