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Original article

THE CONTENT OF VOLATILE ORGANIC COMPOUNDS IN BUILDING MATERIALS AS A RISK FACTOR FOR PUBLIC HEALTH

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Abstract

Background. Emissions of volatile organic compounds (VOCs) emitted by building materials pose a serious threat to human health, especially in closed spaces. Research in this area has been conducted by the World Health Organization (WHO), the Environmental Protection Agency, the Harvard School of Public Health, and others. The presented study examines the effects on human health of VOCs emitted by building materials used for indoor and outdoor decoration.

Materials and methods. VOC emissions from six types of building materials were determined by laboratory method in a climatic chamber. Based on the results obtained, the public health risk associated with emissions of carcinogenic and non-carcinogenic organic compounds was calculated and assessed.

Results. The results revealed that the total lifetime carcinogenic risk for four out of six types of building materials (tile adhesive, PVC window frames, mineral wool, putty) corresponds to the alarming level which requires special risk-reduction measures. The total non-carcinogenic risk for all the building materials investigated is at the maximum permissible or minimum levels, with the exception of tile adhesive, which has a high level of risk.

Keywords: volatile organic compounds; hazard index; carcinogenic risk; public health risk; certification

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Научная статья

СОДЕРЖАНИЕ ЛЕТУЧИХ ОРГАНИЧЕСКИХ СОЕДИНЕНИЙ В СТРОИТЕЛЬНЫХ МАТЕРИАЛАХ КАК ФАКТОР РИСКА ДЛЯ ЗДОРОВЬЯ НАСЕЛЕНИЯ

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Аннотация

Обоснование. Выделения летучих органических соединений (ЛОС) из строительных материалов представляют серьезную угрозу для здоровья человека, особенно в закрытых помещениях. Исследования в этой области проводились Всемирной организацией здравоохранения (ВОЗ), Агентством по охране окружающей среды, Школой общественного здравоохранения Гарвардского университета и др. В представленном исследовании рассмотрено воздействие на здоровье человека летучих органических соединений, выделяемых строительными материалами, используемыми для внутренней и внешней отделки помещений.

Материалы и методы. Эмиссии ЛОС от шести видов строительных материалов определялись лабораторным способом в климатической камере. На основании полученных результатов были проведены расчет и оценка риска для здоровья населения, связанного с эмиссией канцерогенных и неканцерогенных органических соединений.

Результаты. Выявлено, что суммарный пожизненный канцерогенный риск для четырех из шести видов строительных материалов (плиточный клей, оконные рамы ПВХ, минеральная вата, шпаклевка) соответствует настораживающему уровню, что требует проведения специальных мероприятий по его снижению. Суммарный неканцерогенный риск для всех исследованных строительных материалов находится на предельно допустимом уровне или минимальном уровне, за исключением плиточного клея, риск от которого соответствует высокому уровню.

Ключевые слова: летучие органические соединения; индекс опасности; канцерогенный риск; риск для здоровья населения; сертификация

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Introduction

As sustainable construction practices develop, there is growing attention to how a building and its interior decoration can affect human health. An integral part of a healthy building is indoor air quality [7].

These issues were once addressed by the WHO in its report on indoor air quality [22], and the US Environmental Protection Agency in its Indoor Air Quality (IAQ) section [21]. A 2013 study in the journal *Environmental Health Perspectives* linked exposure to formaldehyde (often emitted by chipboard and adhesives) with an increased risk of leukemia [18]. The work of researchers from Iran showed a link between VOCs and symptoms of “sick building syndrome” [19]. Research from the Harvard T.H. Chan School of Public Health linked high levels of VOCs with cognitive impairment [16]. The Department of Medical Sciences, Occupational and Environmental Medicine at Uppsala University in Sweden is investigating the link between VOC exposure in adults from Northern Europe and asthma and allergic reactions [20]. It has been found that sensitive groups of the population such as children, pregnant women, the elderly, people with chronic diseases (asthma, diabetes, immunodeficiencies) are especially susceptible to VOCs.

Volatile organic compounds (VOCs) are common pollutants emitted into the air by various building materials that can potentially cause both short-term and long-term adverse health effects [3]. Declaration of conformity for building materials is a procedure confirming compliance with mandatory requirements that are approved in regulatory documents, including [5; 6; 9-11].

With reference to chemical products that are required for the construction and repair works of various structures, it is necessary to obtain a state registration certificate (hereinafter - SRC). The presence of the SRC confirms that the product is included in this register, complies with established hygienic and sanitary-epidemiological rules. For example, a certificate is required for varnishes, enamels, polyurethane foams, sealants, mastics, putties, grouts, resins, solvents and other materials. The SRC is valid for an indefinite period of time. If

construction materials are not included in the list of those subject to mandatory inspection in accordance with the decision of the Customs Union Commission No. 299 Decision of May 28, 2010 “On sanitary measures in the Eurasian Economic Union” [17] and are not subject to a certificate, it is necessary to obtain an expert certificate on them. This document is also valid indefinitely and confirms hygienic safety in terms of the release of harmful substances (in some cases, in terms of radiological safety).

Thus, certification of construction materials plays an important role in maintaining both human health and the environment [1; 17].

Consequently, this procedure is designed to protect consumers from hazardous products, provide reliable, objective and accurate information about their quality and safety for human health and the environment [8].

Materials and methods

The objects of the study were six types of Russian-made building materials received for the product quality certification procedure: plasterboards, tile adhesive, polyvinyl chloride linoleum (hereinafter referred to as PVC), mineral wool, plastic windows (their PVC frame) and putty. In order to maintain confidentiality, the names of the companies and trademarks of the manufacturers are concealed.

To determine the emission of thirty-eight volatile organic compounds from the studied building materials, thirteen of which were classified as carcinogenic substances, the GOST ISO 16000-6-2016 [5] interstate standard was used. Samples of building materials were placed in a climatic chamber for 24 hours in accordance with GOST 30255-2014 [6]. To measure the concentrations of VOCs, a gas chromatograph “Kristallux-4000M” (designed for automated analysis of chemical compounds and included in the State Register of Measuring Instruments) was used. The experimental system (the climatic chamber) contained a stainless-steel test chamber, a clean air generation and humidification system, an air mixing system and an environmental monitoring system. The size of the test chamber corresponded to the intended use of the building products in relation to the reference room, with an area of 20 m². The test chamber was connected to an electronic controller, which controlled the test time, air flow and air change rate. To ensure adequate air mixing, a small fan was constantly running inside the chamber. The air velocity above the test samples ranged from 0.1 m/s to 0.3 m/s. The emission chamber was hermetically sealed. The volume of the chamber was 0.1 m³. During the experimental period, the air change rate was 0.5 m/s, the temperature inside the chamber was 23 ± 0.5 °C, and the humidity was 50 ± 3%.

The risk assessment from VOCs exposure was carried out in accordance with the methodology for health risk assessment of air pollution by chemicals, which is based on numerous scientific studies and recommendations of the World Health Organization (WHO). The study used the new, which came into force in 2024, "Guidelines for public health risk assessment of exposure to chemicals polluting the environment P 2.1.10.3968-23 [12].

The following standard values of exposure factors were taken into account to calculate the individual lifetime carcinogenic risk to human health with chronic inhalation exposure to the body (CR): concentrations of harmful substances in the air (C), mg/m³; duration of inhalation exposure (ED), years; inhalation rate (IR), m³/day; exposure averaging period (AT), years; human body weight (BW), kg; frequency of exposure during the year (EF), days/year; as well as the factors of carcinogenic potential (SF_i) values (mg/(kg day))⁻¹. Based on these parameters, the average daily lifetime doses of substances entering the human body (LADD_i) (formula 1) and the values of individual carcinogenic risk (formula 2) were calculated.

$$\text{LADD}_i = C \cdot \text{IR} \cdot \text{EF} \cdot \text{ED} / \text{BW} \cdot \text{AT} \cdot 365, \text{ mg}/(\text{kg} \cdot \text{day}) \quad (1)$$

$$\text{CR}_i = \text{LADD}_i \cdot \text{SF}_i \cdot g \quad (2),$$

where CR_i is the value of individual carcinogenic risk; LADD_i is the average long life daily dose, mg/(kg day); SF is the carcinogenic potential factor, (mg/(kg day))⁻¹; g is the severity coefficient of malignant neoplasms (cancer).

The total lifetime carcinogenic risk from combined exposure to all studied substances (CR_Σ) was considered as additive (formula 3) [11].

$$\text{CR}_\Sigma = \Sigma \text{CR}_i \quad (3)$$

To calculate non-carcinogenic risk (hazard coefficients, HQ_i), the following formula was used:

$$\text{HQ}_i = C_i / \text{RfC}_i \quad (4),$$

where C_i is the substance concentration in the room air, mg/m³; RfC_i is the reference (safe) concentration, mg/m³.

For calculating the total non-carcinogenic risk (hazard index, HI), formula 4 is used:

$$\text{HI} = \Sigma \text{HQ}_i \quad (5),$$

where HQ_i are the hazard coefficients for various chemical substances polluting indoor air.

Results and discussion

As a result of the qualitative and quantitative study of the air in the gas chamber for the content of thirty-eight VOCs using the gas chromatographic

method for six types of building materials, the concentrations presented in Table 1 were obtained.

Table 1.

VOCs content in building materials emissions, mg/m³

#	Substance / Material	Plasterboards	Tile adhesive	Lino-leum	Mineral wool	PVC window frames	Putty
1	1,2,4- Trimethylbenzene	0.0007	0.0018	0.0012	0.0006	BDL	0.0007
2	1,2- Dichloroethane	0.0015	0.0019	0.0018	0.0009	0.0016	0.0015
3	N- propanol	0.0013	0.0109	0.0014	0.0144	BDL	0.0051
4	Acrylonitrile	BDL	0,0008	BDL	BDL	BDL	BDL
5	Ammonia	BDL	BDL	0.015	BDL	BDL	0.0553
6	Acetaldehyde	BDL	BDL	BDL	BDL	0.0006	BDL
7	Acetone	0.0079	0.0095	0.0025	0.014	0.0065	0.0187
8	Acetonitrile	0.0014	0.0008	0.0011	0.0017	BDL	0.0015
9	Benzene	0.0023	0.0179	BDL	BDL	BDL	0.0011
10	Butyl acetate	0.0010	0.0027	0.0007	0.0014	0.0073	0.0020
11	Vinyl acetate	0.0006	BDL	BDL	BDL	BDL	BDL
12	Hexane	0.0035	0.0714	0.0011	0.0120	BDL	0.0199
13	Heptane	0.0010	0.0021	0.0011	0.0015	BDL	0.0018
14	Isobutanol	0.0008	0.0006	BDL	0.0006	BDL	0.0019
15	Isobutyl acetate	BDL	0.0007	BDL	0.0005	BDL	0.0009
16	Isopropyl acetate	BDL	0.0014	0.0009	0.0005	0.0010	0.0008
17	Isopropylbenzene	BDL	BDL	BDL	BDL	BDL	BDL
18	M,p-xylene	0.0008	0.0012	0.0011	0.0016	BDL	0.0029
19	Methanol	BDL	0.0007	0.0007	0.0007	BDL	0.0021
20	O-xylene	0.0014	0.0028	0.0012	0.0029	0.0007	0.0012
21	Propylbenzene	0.0015	BDL	0.0009	0.0009	BDL	0.0008
22	Styrene	0.0008	BDL	0.0014	BDL	0.0006	0.0025
23	Tetrachloromethane	0.0014	0.0252	BDL	0.0210	0.0112	0.0337
24	Tetrachloroethylene	BDL	BDL	0,0007	BDL	BDL	0.0005
25	Toluene	0.0013	0.0017	0.0015	0.0025	0.0013	0.0030
26	Trichloroethylene	BDL	0,0009	BDL	BDL	BDL	0.0006
27	Phenol	BDL	BDL	0.0040	BDL	BDL	BDL
28	Formaldehyde	BDL	BDL	BDL	BDL	BDL	0.0021
29	Chlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL
30	Chloroform	0.0016	0.0031	0.0012	0.0026	0.0063	0.0177
31	Cyclohexane	BDL	BDL	BDL	BDL	0.0005	0.0007
32	Cyclohexanone	0.0009	BDL	BDL	BDL	BDL	BDL
33	Epichlorohydrin	0.0021	0.0066	0.0015	BDL	0.0005	BDL

34	Ethanol	0.0009	0.0030	BDL	0.0017	0.0005	0.0008
35	Ethyl acrylate	0.0010	BDL	0.0005	BDL	BDL	0.0012
36	Ethyl acetate	0.0007	0.0013	BDL	0.0014	BDL	0.0006
37	Ethylbenzene	BDL	BDL	BDL	BDL	BDL	BDL
38	Ethoxyethyl acetate	0.0009	0.0010	0.0010	0.0027	BDL	0.0008

BDL: Below detection limit

As follows from Table 1, the highest concentrations of VOCs emitted from gypsum boards are acetone, from board adhesives – hexane, from linoleum and putty – ammonia, from mineral wool and PVC window frames – tetrachloromethane. None of the obtained concentrations exceeded the RfC_i value [12]. The largest number of studied VOCs was determined in putty (30 items), the smallest – in PVC window frames (13 items).

Based on the obtained concentrations, the values of carcinogenic potential factors (SF_i) and reference concentrations (RfC_i) taken from the Guide [12], the carcinogenic and non-carcinogenic risks of substances released into indoor air were calculated (Tables 2, 3).

Table 2.

Values of carcinogenic risk levels

#	Substance / Material	Tile adhesive	Plaster-boards	Linoleum	Mineral wool	PVC window frames	Putty
1	1,2- Dichloroethane	0.000047	0.000037	0.000045	0.000022	0.003068	0.000037
2	Acrylonitrile	0.000053	-	-	-	-	-
3	Acetaldehyde	-	-	-	-	0.000001	-
4	Benzene	0.000132	0.000017	-	-	-	0.000008
5	Styrene	-	0.0000001	0.000001	-	0.000001	0.000001
6	Tetrachloromethane	0.000366	0.000020	-	0.000305	0.000163	0.000489
7	Tetrachloroethylene	-	-	0.0000001	-	-	0.0000001
8	Trichloroethylene	0.000002	-	-	-	-	0.000001
9	Formaldehyde	-	-	-	-	-	0.000026
10	Chloroform	0.000007	0.000004	0.000003	0.000006	0.000014	0.000039
11	Epichlorohydrin	0.000008	0.000002	0.000002	-	0.000001	-
12	Ethyl acrylate	-	0.000013	0.000007	-	-	0.000016
13	Ethylbenzene	-	-	-	-	-	-
Total risk, CR_i		0.000614	0.000094	0.000057	0.000333	0.000218	0.000618

Let us discuss the results of calculations of carcinogenic health risks for each type of building material:

Tile adhesive. The total carcinogenic risk from substances emitted by tile adhesive was 6.1×10^{-4} . This corresponds to an alarming, unacceptable risk level

for the population ($1.1 \times 10^{-4} - 1.0 \times 10^{-3}$) [12]. In this case, the quality certificate for this product should not be issued. Carbon tetrachloride makes the greatest contribution to the level of carcinogenic risk ($R = 3.7 \times 10^{-4}$).

Gypsum cardboard. The total carcinogenic risk from substances emitted by gypsum cardboard was 9.4×10^{-5} , which corresponds to a low, maximum permissible risk level ($1.1 \times 10^{-6} - 1.0 \times 10^{-4}$). It is at this level that most foreign and internationally recommended hygienic standards for the population as a whole are established. The greatest contribution to the level of carcinogenic risk is made by 1,2-dichloroethane ($R = 3.7 \times 10^{-5}$).

Linoleum. The total carcinogenic risk from substances emitted by linoleum was 5.7×10^{-5} . This also corresponds to the maximum permitted risk level ($1.1 \times 10^{-6} - 1.0 \times 10^{-4}$). The greatest contribution to the level of risk is made by 1,2-dichloroethane ($R = 4.5 \times 10^{-5}$).

Mineral wool. The total carcinogenic risk from substances emitted by mineral wool was 3.3×10^{-4} . This corresponds to an alarming level of risk, which is unacceptable for the population ($1.1 \times 10^{-4} - 1.0 \times 10^{-3}$). In this case, the quality certificate should be refused for this product. Carbon tetrachloride makes the greatest contribution to the level of carcinogenic risk ($R = 3.1 \times 10^{-4}$).

PVC window frames. The total carcinogenic risk from substances emitted by PVC window frames was 2.2×10^{-4} , which also corresponds to an alarming level of risk. In this case the quality certificate should also be refused for this product. Carbon tetrachloride makes the greatest contribution to the level of carcinogenic risk ($R = 1.6 \times 10^{-4}$).

Putty. The total carcinogenic risk from substances emitted by putty was 6.2×10^{-4} , which corresponds to an alarming level of risk, which is unacceptable for the population. In this case, as in the previous ones, the certificate should be refused for the studied product. The greatest contribution to the level of carcinogenic risk is made by carbon tetrachloride ($R = 4.9 \times 10^{-4}$).

Table 3.

Non-carcinogenic risk level values

#	Substance / Material	Tile adhesive	Plaster-boards	Linoleum	Mineral wool	PVC window frames	Putty
1	1,2,4-Trimethylbenzene	0.3	0.116667	0.2	0.1	-	0.116667
2	1,2-Dichloroethane	0.00475	0.00375	0.0045	0.00225	0.004	0.00375
3	N-propanol	0.014932	0.001781	0.001918	0.019726	-	0.006986
4	Acrylonitrile	0.4	-	-	-	-	-
5	Ammonia	-	-	0.15	-	-	0.553

6	Acetaldehyde	-	-	-	-	0.066667	-
7	Acetone	0.000304	0.000253	0.000080	0.000449	0.000208	0.000599
8	Acetonitrile	0.013333	0.023333	0.018333	0.028333	-	0.025
9	Benzene	0.596667	0.076667	-	-	-	0.036667
10	Butyl acetate	0.003857	0.001429	0.001	0.002	0.010429	0.002857
11	Vinyl acetate	-	0,003	-	-	-	-
12	Hexane	0.357	0.0175	0.0055	0.06	-	0.0995
13	Heptane	0.0006	0.000286	0.000314	0.000429	-	0.000514
14	Isobutanol	0.0004	0,000533	-	0,0004	-	0.001267
15	Isobutyl acetate	0.000722	-	-	0.000515	-	0.000928
16	Isopropyl acetate	0.001	-	0.000643	0.000357	0.000714	0.000571
17	Isopropylbenzene	-	-	-	-	-	-
18	m,p-xylene	0.012	0.008	0.011	0.016	-	0.029
19	Methanol	0.000175	-	0.000175	0.000175	-	0.000525
20	O-xylene	0.028	0.014	0.012	0.029	0.007	0.012
21	Propylbenzene	-	0.075	0.045	0.045	-	0.04
22	Styrene	-	0.0008	0.0014	-	0.0006	0.0025
23	Tetrachloromethane	0.63	0.035	-	0.525	0.28	0.8425
24	Tetrachloroethylene	-	-	0.02	-	-	0.014286
25	Toluene	0.00425	0.00325	0.00375	0.00625	0.00325	0.0075
26	Trichloroethylene	0.0225	-	-	-	-	0.0125
27	Phenol	-	-	0.666667	-	-	-
28	Formaldehyde	-	-	-	-	-	0.7
29	Chlorobenzene	-	-	-	-	-	-
30	Chloroform	0.031633	0.016327	0.012245	0.026531	0.064286	0.180612
31	Cyclohexane	-	-	-	-	0.000083	0.000117
32	Cyclohexanone	-	0.0009	-	-	-	-
33	Epichlorohydrin	6.6	2.1	1.5	-	0.5	-
34	Ethanol	0.00003	0.000009	-	0.000017	0.000005	0.000008
35	Ethyl acrylate	-	0.020833	0.010417	-	-	0.025
36	Ethyl acetate	0.000406	0.000219	0.000156	0.000438	-	0.000188
37	Ethylbenzene	-	-	-	-	-	-
38	Ethoxyethyl acetate	0.003333	0.003	0.003333	0.009	-	0.002667
Total risk, HI		9.025892	2.522536	2.468431	0.871869	0.937242	2.717708

Let us discuss the results of non-carcinogenic risk calculations for each type of building material.

Tile adhesive. The total non-carcinogenic risk (hazard index) for chronic exposure to the substances under study on the human body was 9.0, which, according to the Guidelines [12], corresponds to a high level of non-carcinogenic risk (HI>6). The risk is dangerous, since in this situation, as a rule, there is a reliable tendency for non-specific pathology to increase with the appearance of

isolated cases of specific pathology. Epichlorohydrin makes the greatest contribution to the level of non-carcinogenic risk for chronic exposure ($HQ=6.6$).

Plasterboards. The total non-carcinogenic risk (hazard index) for chronic exposure to the human body was 2.5, which corresponds to the maximum permitted level of non-carcinogenic risk ($3.0>HI>1.1$). Permitted risk levels are subject to constant monitoring. At such risk levels, additional measures to reduce the risk to human health should be planned and implemented. The greatest contribution to the level of non-carcinogenic risk in case of chronic exposure is made by epichlorohydrin ($HQ=2.1$).

Linoleum. The total non-carcinogenic risk (hazard index) of chronic exposure to the human body also amounted to 2.5, which corresponds to the maximum permitted level of non-carcinogenic risk ($3.0>HI>1.1$). The greatest contribution to the level of non-carcinogenic risk in case of chronic exposure is also made by epichlorohydrin ($HQ=1.5$).

Mineral wool. The total non-carcinogenic risk (hazard index) of chronic exposure to the human body amounted to 0.9, which corresponds to the minimum risk level ($1.0>HI$). Such a risk can be considered acceptable, since in this situation, as a rule, there are no unfavorable medical and environmental trends. Carbon tetrachloride makes the greatest contribution to the level of non-carcinogenic risk in case of chronic exposure ($HQ=0.53$).

PVC window frames. The total non-carcinogenic risk (hazard index) of chronic exposure to the human body was 0.9, which also corresponds to the minimum risk level ($1>HI$). As in the previous cases, epichlorohydrin makes the greatest contribution to the level of non-carcinogenic risk in case of chronic exposure ($HQ=0.5$).

Putty. The total non-carcinogenic risk (hazard index) of chronic exposure to the human body was 2.7, which corresponds to the maximum permitted level of non-carcinogenic risk ($3.0>HI>1.1$). Such risk levels are subject to constant monitoring, additional measures to reduce its level should be planned and carried out. Tetrachloromethane and formaldehyde make the greatest contribution to the level of risk ($HQ=0.84$ and 0.7 , respectively).

Conclusion

Therefore, the study assessed the risk to human health from indoor air pollution due to VOC emissions from building materials.

Having analyzed the results, it can be concluded that the total lifetime carcinogenic risk for four out of six types of building materials (tile adhesive, PVC window frames, mineral wool, putty) corresponds to an alarming risk level

($1.1 \times 10^{-4} - 1.0 \times 10^{-3}$), which is acceptable only for work areas, but unacceptable for the population. The greatest contribution to this risk level is made by carbon tetrachloride and 1,2-dichloroethane, which belong to the second hazard class.

The carcinogenic risk from the use of plasterboards and linoleum corresponds to the maximum permissible level of risk to human health, which is subject to constant monitoring and additional measures to reduce it. In the case of building materials, given the possibility of using several materials at once in one room, it is necessary to refuse to issue quality certificates for such products.

The total non-carcinogenic risk during chronic exposure to the substances studied varies depending on the type of building material. In three of the six types studied (plasterboards, linoleum, putty), the hazard index corresponded to the maximum permissible level of non-carcinogenic risk ($3.0 > HI > 1.1$). Such risk levels are subject to constant monitoring, and in the case of building materials, due to the impossibility of such monitoring in domestic conditions, it was also recommended to refuse quality certificates for these products. A high level of non-carcinogenic risk ($HI > 6$) was identified for tile adhesive, which also excludes the possibility of issuing a quality certificate. The hazard index for the use of mineral wool and PVC window frames corresponds to the minimum risk level ($1 > HI$).

Thus, it can be concluded that the most environmentally friendly of the materials studied were plasterboards and linoleum (HI at the lower limit of the average level, CR low), as well as mineral wool and PVC window frames (HI low, CR at the lower limit of the average level).

The most dangerous in terms of risk to human health was tile adhesive (HI high, R approaching the upper limit of the alarming level). Such a risk is unacceptable for either the population or professional groups. Considering the fact that the use of this product is not limited to floor finishing (it is also used for other walls of the room: showers, bathrooms, kitchens, corridors), when choosing tile adhesive, you should choose only those varieties that have passed product quality certification. The assessment of the public health risk from inhalation of volatile organic compounds emitted from building materials into indoor air was carried out based on the VOC concentration data obtained at a chamber temperature of -23 ± 0.5 °C and humidity of $-50 \pm 3\%$. Changes in microclimatic parameters in this study (temperature and humidity), as well as ventilation air exchange, were not modeled. However, we note that an increase in indoor temperature during the heating season and high humidity are important factors influencing the increase in VOC emissions [2]. Thus, taking into account the seasonal variability of indoor temperature and humidity, the calculation of the public health risk may show an unacceptable level for many building materials.

Volatile organic compounds have a number of physical and chemical properties (low vapor pressure, high adsorption capacity, tendency to polymerization processes, reactivity to the formation of secondary toxic compounds depending on microclimatic parameters, leading to an increase in both non-specific and specific pathology. It should also be noted that the obtained results of the risk from VOC emissions from building materials were considered separately for each of the studied products, which means that during the actual operation of a room with finishing, where several types of such materials were used simultaneously, the carcinogenic and non-carcinogenic load on the health of the owners will increase.

In case when uncertified products have already been used in the finishing of domestic premises and it is not possible to replace them, the following recommendations should be followed:

- Installation of air exchange systems sufficient to ensure the flow and circulation of clean air into the premises. If it is not possible to implement these measures, it is recommended to increase the air exchange rate through ventilation.
- Monitor indoor microclimate parameters to ensure their optimal values.
- Use so-called filter plants that can purify the air and trap pollutants from the air [14]. Such plants include: ivy (*Hedera helix*), bowstring hemp (*Sansevieria trifasciata*), peperomia (*Peperomia obtusifolia*), spider plant (*Chlorophytum comosum*) and waringin (*Ficus benjamina*) [15].

As for the certification procedure itself, the authors recommend making voluntary products certification a mandatory procedure and implementing it taking into account the health risk assessment, since it is an important measure to protect human health from the possible development of environmentally induced pathologies.

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