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Ventilation impact on VOC concentration caused by building materials

Влияние вентиляции на концентрацию ЛОС, вызванных строительными материалами

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Ключевые слова: ЛОС; вентиляция; здания; климатическая камера; краска; герметик; спрей

Abstract. Many of building products emit volatile organic compounds (VOCs) therefore reducing the indoor air quality. The emitted amount and pollution type depends on each specific source. This paper analyses the VOC concentration change caused by such sources as sprayable window cleaner, aroma candles, sprayable air refresher, waterborne acryl-based paint, solvent based paint and acrylic based hermetic sealant. The tests are done at both closed and ventilated climatic chamber conditions. The results show that three different types of VOC concentration change dynamics can be separated depending on the pollution source. If the room is ventilated according to the local regulations the threshold level which indicates hazardous environment for persons is exceeded for 12 hours after applying the pain at given conditions. The obtained data can be used for future studies and to develop high precision methods of VOC concertation prediction and serve as an information source for future ventilation standard development.

Аннотация. Многие строительные изделия выделяют летучие органические соединения (ЛОС), в результате чего снижается качество воздуха в помещении. Величина и тип загрязнения зависят от конкретного источника. В данной статье анализируется изменение концентрации ЛОС, вызванное такими источниками, как распыляемый очиститель для окон, ароматические свечи, распыляемый освежитель воздуха, акриловая краска на водной основе, краска на основе растворителя и герметик на акриловой основе. Испытания проведены в климатической камере как в герметичных, так и в вентилируемых условиях. Результаты показывают, что в зависимости от источника загрязнения могут быть выделены три разных типа динамики изменения концентрации ЛОС. Если помещение вентилируется в соответствии с местными нормами, то пороговый уровень превышается в течение 12 часов, следовательно возникает опасная среда для людей. Полученные данные могут быть использованы для будущих исследований и разработки высокоточных методов прогнозирования концентрации ЛОС, а также могут служить источником информации для разработки новых стандартов вентиляции.

1. Introduction

Volatile organic compounds are carbon-base compounds with a vapor pressure high enough to evaporate and enter the atmosphere under atmospheric pressure and participate in atmospheric photochemical reactions. Many different types of VOCs can be found in the air, such as alkanes, halogenated hydrocarbons, aromatic hydrocarbons, terpenes, aldehydes, ketones and alcohols. Some of these compounds are toxic or cancerogenic therefore have limited values for airborne concentrations in order to avoid harmful effects on human health. Depending on the boiling point of the VOCs they are divided in several subgroups – very volatile (VVOC), volatile and semi-volatile organic compounds (SVOC). The VVOCs are so volatile that they are almost entirely found in the gas state while SVOC, although found in indoor air, will be mostly in solid or liquid form on surfaces of building materials, furniture and dust. Also, according to study [1] the VOC pollution can be divided in two types – primary and secondary. The primary

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emission is defined as the physical release of VOCs from new products, while the secondary emission is released after the chemical reactions with existing indoor substances and surfaces.

VOCs found in buildings are exceptionally dangerous to humans, because we spend the largest part of the day indoors where the concentration can reach 10 times higher amount than compared to the outside. A wide range of consumer products and personal hygiene products release a significant amount of VOCs during their use. The main sources of VOCs are building materials, decoration materials, furniture, cleaning products, dry cleaners, paints, varnishes, solvents, glues, aerosols, refrigerants, fungicides, bactericides, cosmetics and textiles, household appliances, air fresheners, clothing, tobacco smoke and visible mold [2]. Insufficient indoor air exchange can result in an accumulation of VOCs and serving as a potential risk for human health [3]. VOCs emitted from many building materials are taken as the major sources causing poor indoor air quality, which negatively affect people’s comfort, health and productivity [4; 5]. This can be especially notable in countries where large amount of old buildings is present and high potential of renovation projects are possible with feasible payback period [6]. As for example in case of schools and kindergartens the renovation usually occurs during the summer period and is finished only couple of days before the start of next semester when all children return to the premises [7].

One of the most common VOCs found in buildings is formaldehyde which is used to produce phenolic, urea, melamine and polyacetyl resin adhesives and binders for wood products, paper and synthetic fiber products. Its application in wood products, carpets, paints and varnishes causes it to be the main source of formaldehyde in the premises. As a study of energy efficient houses in Lithuania shows, formaldehyde was the only pollutant that exceeded the limit values for this chemical in all studied homes [8]. The formaldehyde also is generated by particleboards and plywood, and the studies show how the amount of emitted VOCs depends on room temperature and moisture content [9; 10]. This could be linked to a study that shows the change of indoor air depending on building characteristic and outside parameters [11]. Different study [12] showed that the toluene was the most abundant indoor VOC and that the indoor concentrations of certain VOCs were significantly higher for the one-month post-occupancy stage than the pre-occupancy stage, which was likely attributable to emissions from furniture and household products used by inhabitants after moving in, as well as building finishing materials.

In general, it is necessary to determine the TVOC value to judge if the indoor air quality is appropriate for long term stay. According to a study [13] it is suggested that the upper limit of TVOC should not exceed 300 $\mu g/m^3$. This value is based on the data collected from a study in German residential houses. At the same time, the same study stresses that the concentration level of different VOC classes, like alkanes, aromatic hydrocarbons, terpenes, halogens, esters, should also be regulated.

To make predictions and to understand how the VOC level changes due to different common household pollution sources it is necessary to perform experiments in controlled environment. Such experiments have already been performed by various authors focusing on different pollutants. For example, a study [14] analyzed how seven most commonly occurring compounds discovered (benzene, toluene, methylethylketone, styrene, methyl group, ethyl alcohol and terpenoid) increase the VOC concentration at three different volumes of 0.1, 0.5 and 1.0 ml in 5 m^3 large space without air exchange. The results showed that most of the products seem to have very little short-term effect. However, if exposed over certain durations, this can lead to enhanced health risks. Interesting measurements regarding the VOC emissions from various aroma candles was performed in a study [15] providing results that indicate the high amount of released formaldehyde especially when the candles are lit. This must be taken into account, for example, in historic buildings like churches, where a high number of candles can be simultaneously lit to choose the necessary minimal amount of ventilation [16; 17]. In study [18] VOC emissions from several consumer and commercial products like body wash, dishwashing detergent, air freshener, windshield washer fluid, lubricant, hair spray, and insecticide, were studied and compared. The spray products were found to emit the highest amount of VOCs while the body wash products showed the lowest VOC contents.

The paints are one of the most common and noticeable sources of VOC in indoor environment. In near past almost all paint was solvent based. Such paints contain higher levels of VOCs compared to water-based paints and they evaporate and release VOCs into the atmosphere resulting in a strong odor and toxic impact on the environment. Nowadays due to local regulations and environmental protection directives the use of solvent based paints is noticeably reduced. Measurements in a study [19] regarding the VOC concentration increase caused by solvent paints in ventilated chamber was performed. The results showed that it takes about 12 h for the chamber to be ventilated if the air exchange rate is about 9 times and a method of concentration prediction was developed. In different study [20] low-VOC and zero-VOC paints was analyzed. The data showed that in these type of paints, part of the VOCs is replaced by SVOCs. Chemical compounds, which are often used as solvents in the usual colors still remain in the "green" colors, albeit to a lesser extent. At the same time, during the 72 hours test period the tested paints still released a

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high concentration of pollutants. Based on this result, the differences between traditional colors and the low-VOC and zero-VOC paints are less significant than expected.

This paper focuses on widening the existing information regarding the VOC emissions from various common pollution sources. In most cases the only notice written on commonly used building materials is that they should be used in well ventilated rooms. However, no additional information what is meant by this is given. Therefore, one of the objectives of this study is to measure the VOC level caused by using different type of paints in environment that simulates the ventilation rate according to local regulations. The obtained information can serve as a future data source to develop methodology on how to predict the VOC concentration after applying some of the sources. During the tests the comparison between solvent and acrylic based paints will also be performed. The experiments will be done in controlled environment in climatic chamber. At first the chamber will be unventilated while in second set of measurements it will be ventilated according to local regulations [21] to study if under such conditions the environment is not harmful for human health.

2. Methods

The experiments were carried out at a climatic chamber with dimensions of 3 by 4 m and ceiling height of 2.3 m, thus the total volume of chamber is 27.6 m^3. The climatic chamber was tightly sealed therefore making it almost perfectly air tight. The climatic chamber was equipped with VOC measuring sensor, ILH with VOC measuring range of 450–2000 ppm. The VOC sensor detects wide variety of hydrocarbons such as cigarette smoke, exhaled breathing air, solvent vapours, building material emissions and cleaning agent vapours. The data was continuously logged during the time of experiment and the measured values were noted after each 15 seconds. Information regarding air temperature, relative humidity and CO_2 levels also was measured. To ensure that the pollution is equally spread in the chamber a small fan was placed in the middle of the room.

The experiment was divided into two phases. During the first phase various VOC sources and sources with different concentration were introduced in the unventilated climatic chamber one by one to. Afterwards the climatic chamber was shut, and measurements of VOC concentration changes were performed until the steady state was reached. Therefore, it was possible to determine the strength of different pollution sources and the time it takes to reach steady state depending on the introduced concentration of each pollution source. After each measuring series the climatic chamber was fully ventilated until VOC reached the background level.

During the second phase the climatic chamber was equipped with ventilator ensuring stable flow of 36 m^3/h which is the minimal necessary amount determined by the local Latvian building norm LBN 211-15 “Residential buildings” that require air flow of 3 m^3/m^2. Afterwards pollution sources of VOC were introduced in the climatic chamber and measurements were started. During this phase it was possible to determine whether and for how long the VOC level exceeds the one stated in the regulations regarding human safety.

The tested pollution sources were as follows: sprayable window cleaner, aroma candles, sprayable air refresher, waterborne acryl-based paint, solvent based paint and acrylic based hermetic sealant. For each of the pollution sources the composition was analysed and the main and most hazardous VOC emitting substance determined. This was done to determine the various danger thresholds levels which are different for each substance. The information regarding the immediate danger threshold, 15 min danger threshold and limit allowed for 8h period per day was obtained after studying international standards [22–24].

For the sprayable window cleaner, the main VOC is ethanol and its compounds. The immediate limit of life hazard of ethanol is 3300 ppm, but for 8h a day period the concentration the limit is 1000 ppm. The composition of the sprayable air refresher with the citrus scent is not given but comparing to a similar product data sheet it is determined that the main VOC emitting substance is limonene. This contaminant poses an immediate risk to human health if the concentration level of 20 ppm is exceeded. Aromatic candles contain cinnamon aldehyde, eugenol and benzyl benzoate. These substances do not indicate any immediate danger to humans according to available sources.

The solvent-based paint compound contains mostly white spirit (90–100 % aliphatic and alicyclic hydrocarbons; < 10 % terpenes and terpenoids; < 0.1 % benzene), which is thought to be the main volatile organic compound. The solvent-based paint contamination immediate danger threshold limit is 750 ppm, but the concentration limit for 15 minutes period is 440 ppm while a concentration limit for 8 hr working day is 85 ppm.

The composition of acrylic based paint was not specified, but comparing to a similar product data sheet, diuron and ammonia are taken as the main pollutants. From acrylic pollutants, only ammonia has an immediate hazard limit for life – 500 ppm, but the total concentration limit allowed for 8h working day is 35 ppm (dioron -10 ppm + ammonia 25 ppm).

The composition of the acrylic based hermetic sealant indicates that it contains propylene and butylene groups which are accepted as the main VOC elements. The immediate hazard limit for life of acrylic based hermetic sealant contamination is determined to be 20 000 ppm (2-propane-12 000 ppm + n-butane 8 000 ppm) while a concentration limit of 500 ppm (2-propane-400 ppm + n-butane 100 ppm) is allowed for 8h per day.

Figure 1. Pictures showing how the pollution sources - acrylic based hermetic sealant (left side); waterborne acryl-based paint (middle) and solvent based paint (right side), were applied.

3. Results and Discussions

3.1. Sprayable window cleaner

The first measurements were performed with the sprayable window cleaner. It was sprayed directly into the middle of the chamber and for comparison, two different volumes were sprayed. For measurements number one and two the sprayed amount was equal to two full spray presses while for measurements three and four the spray was pressed four times therefore doubling the introduced amount of pollutant.

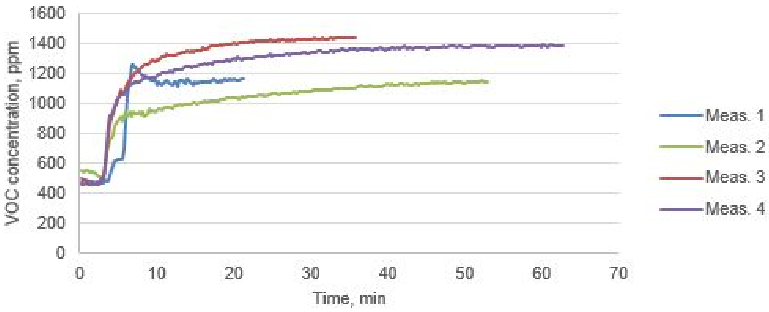

Figure 2. VOC concentration change in time caused by spraying of window cleaner.

To analyze the results, it is necessary to determine the influence of each pollution source therefore it is needed to subtract the background VOC level which is caused by the emissions from existing elements in climatic chamber. As seen from the figures presented in the results section, this background level is not equal for all cases as the VOC level varies during the different experiments. This could be explained due to fact that although after each experiment the rooms were fully ventilated, some of the VOCs could settle to the walls and be released in the air as a secondary pollutant.

As seen from the Figure 2 the total VOC level after the use of a window cleaner if it is sprayed two times is about 1100–1150 ppm, while if the introduced amount of pollution source is doubled then the concentration of total VOCs reaches about 1400 ppm. If we subtract the background VOC concentration, which in specific case is about 500 ppm, then the VOC level increase caused directly by applied window cleaner is 650 ppm and 900 ppm respectively. It means that the VOC has increased by approximately half of the expected rate if double amount is introduced in the room. Therefore, it can be concluded that doubling the pollution source amount does not necessarily mean that the VOC level will also double. This could be explained by the fact that the spray product stays on the surface and does not immediately evaporate into the room and gets released in prolonged period of time. The results obtained in the experiment indicate that the contamination level of VOCs caused by using window washer agent in enclosed space does not pose immediate hazard to human life at given amount as the danger limit for ethanol, which is considered low toxicity, is relatively high – 3000 ppm for immediate risk and 1000 ppm for 8h period. However, it must be noted that under realistic conditions the sprayed amount would be a lot higher and could cause health risk if working indoors in unvented space. If the VOC increase of one spray is adjusted for 1 m^3 of the room than the results show that the window cleaner is causes the VOC level to rise by 7 590 ppm.

3.2. Acrylic based hermetic sealant

The second analysed substance was acrylic based hermetic sealant. It is acrylic polymer based on water which ensures resistance against UV and moisture. Used for filling cracks, repairing surface defects before painting and for indoor window and door sealing. A total of 5 meters of acrylic sealant was applied on a laminated particleboard (older scrap that would not significantly affect the concentration of VOC in the room).

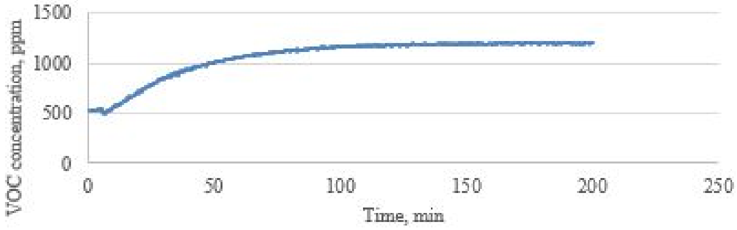

Figure 3. VOC concentration change in time caused by acrylic based hermetic sealant.

By analyzing the Figure 3 which represents the results regarding the VOC emission from acrylic based hermetic sealant it can be seen that the VOC level rapidly rises during the first two hours and then settles at a constant level of 1200 ppm. If the background VOC concentration is subtracted, then it can be estimated that the pollution directly from the sealant is about 700 ppm. It means that the concertation is much lower compared to the one that causes immediate health risk (20 000 ppm) but is slightly above the allowed 8h per day (500 ppm). By knowing that 5 m of sealant was introduced into the room and that the room volume is 27.6 m^3 it can be calculated that 1 m of such sealant gives about 3860 ppm if located 1 m^3 large room.

3.3. Air refresher

Regarding the sources that are used to improve the scent of air, two substances were testes – sprayable air refresher and aroma candles. The air refresher was sprayed in the middle of the room by pressing the spray button for 3 seconds. As for the aroma candles three candles were introduced in the room, but due to fire safety requirements the candles were not lit.

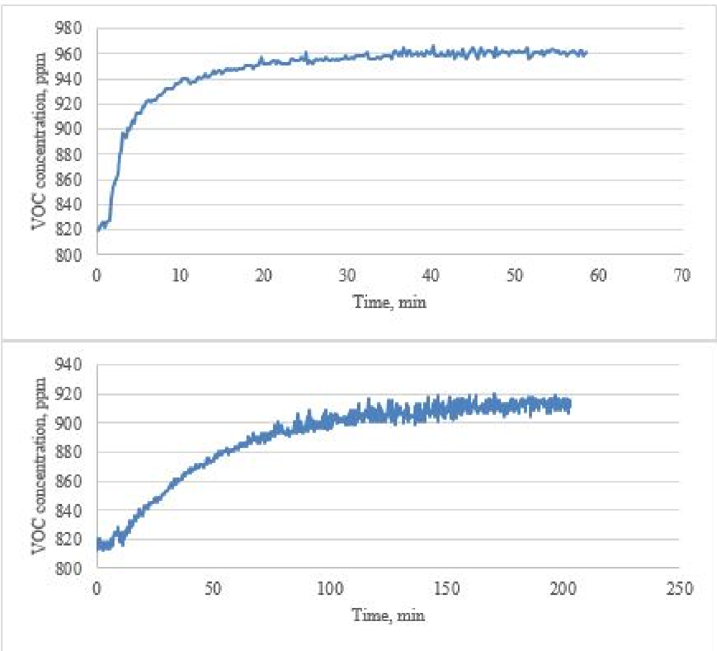

Figure 4. VOC concentration change in time caused by sprayable air refresher (left side) and aroma candles (right side).

The Figure 4 shows how the VOC level rises after air refresher and aroma candles are applied in closed room. It can be seen that in case of air refresher the VOC sensor immediately responds and the maximal level, which is 980 ppm, is reached in about 3 minutes. While for aroma candle the VOC increases noticeably slower and reaches steady state in 2 hours, which is 910 ppm. In both cases the absolute value of VOC increase taking into account the background pollution is similar – 140 and 90 ppm respectively. Although this seams a low number it exceeds the immediate hazard risk of 20 ppm of limonene. However not all of the measured VOC is necessarily linked to this substance as the limonene is only half of the composition of sprayable air refresher. Adjusting the results for 1 m^3 large room and 1 second long spray of air refresher it can be calculated that the VOC would rise by 1288 ppm, while for one aroma candle it would rise by 828 ppm.

3.4. Acryl-based and solvent based paint

To compare how different types of paint emit VOCs waterborne acryl-based paint and solvent based paint was tested. In the first experiment the acryl-based paint was put on 4 m^2 of laminated particleboard. In the second experiment the solvent based paint was first put on 2 m^2 of laminated particleboard, but afterwards also on 0.25 m^2 because of the limitations of measuring device as in case when the paint was put on 2 m^2 the VOC concentration reached 2000 ppm.

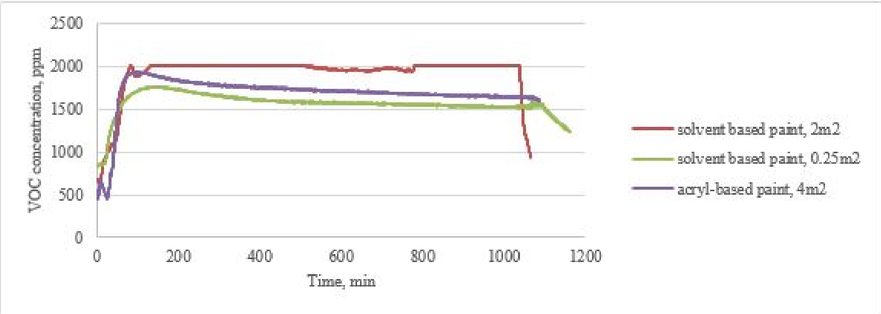

Figure 5. VOC concentration change in time caused by waterborne acryl-based and solvent based paints.

In Figure 5 the comparison between waterborne acryl-based and solvent based paints can be seen. The results show that the VOC emissions from waterborne acryl-based paint is a lot lower than from solvent based paints. In all experiments the maximal VOC level was reached in 1.5 h but then started to slightly decline until reached the steady state level in about 5 hours. For solvent based paint with area of 0.25 m^2 the VOC level stabilizes out at 1550 ppm, while for acryl-based with area of 4 m^2 this level is 1680 ppm. In the absolute values the VOC emissions from acryl-based paint reaches 1450 ppm and stabilizes at 1200 ppm, while from solvent based paint the values are 900 ppm and 700 ppm respectively. If these numbers are adjusted for 1 m^2 of paint at 1 m^3 room, then they read 8 280 ppm for acryl-based paint and 77 280 ppm for solvent based paint. This means that the emission level from solvent based paint is approximately 9 times higher. For both paints the danger threshold for immediate and 8 h period was exceeded. In case of acryl-based paint the immediate hazard level of 500 ppm was exceeded 3 times, while for solvent based paint the threshold level of 750 ppm was exceeded for the first 7 hours.

Afterwards the climatic chamber was equipped with ventilator and the measurements performed on how VOC concentration changes during longer periods if some elements in the room are painted. First the simulation with waterborne acryl-based paint was performed. A total of 3 m^2 of waterborne acryl-based painted surface was introduced into the climatic chamber and the VOC data was logged for almost 3 days.

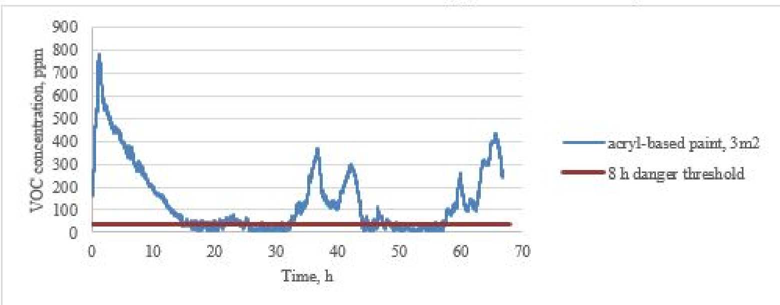

Figure 6. VOC concentration change in ventilated test chamber caused by acryl-based paint.

The second tested substance was solvent based paint. For this test only 0.25 m^2 of painted surfaces were introduced into the climatic chamber as the experience from previous experiments showed that VOC emission from it are a lot more intense. The test was run for 60 hours to see how the day cycle influences the VOC values.

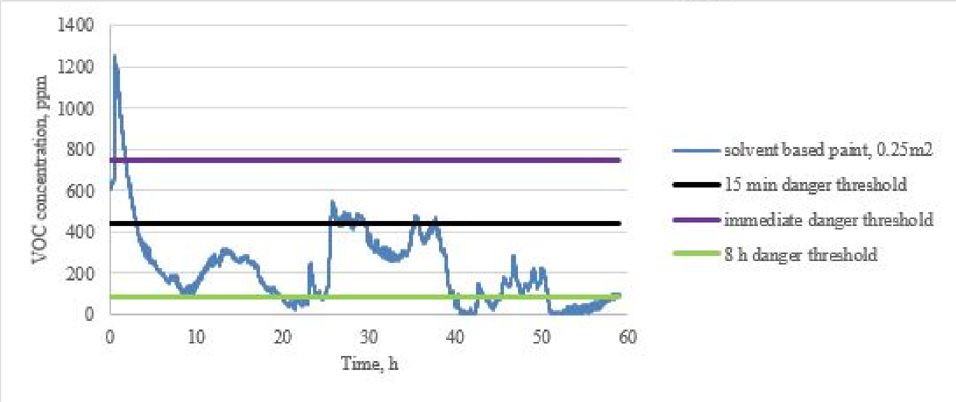

Figure 7. VOC concentration change in ventilated test chamber caused by solvent-based paint.

The Figures 6 and 7 present the results of VOC emissions from waterborne acryl-based and solvent based paints located in ventilated room. They both show that the ventilation does not affect the immediate spike in VOC concentration that reaches the maximum in 1.5 h, the same as in unventilated room. However, the maximal value is slightly decreased if compared to unventilated room. For acryl-based paint it reaches 780 ppm, while for solvent based paint 1200 ppm. The calculated decrease therefore is about 33 %. The further influence of ventilation is also noticeable as the VOC level gets decreased to minimum at around 10-hour time. However, the results also show that there is a periodical increase in the VOC levels during the next days of experiment. This could be explained by the increase in the room temperature during the daytime, which possibly stimulates the reaction of the paint and release of additional VOCs. Also, the graphs show that the room where acryl-based paint is introduced the air quality is mostly harmless for human health if it is ventilated acceding to local regulations. In case of solvent based paint, the situation is different and even if only 0.25 m^2 of such paint is introduced in the room the air quality is not adequate and persons should not be present for more than 15 minutes.

The results also showed that three different types of VOC concentration increase can be defined. The first one is the rapid increase of VOC level if the pollution source is sprayed as aerosol in the air. In such case the maximal VOC level is reached in around 10 minutes. The second type is the slow and stable release of VOCs in the air that occur from materials, like hermetic sealants or aroma candles, that are introduced into the room. In this case the concentration rises following logarithmic scale for about 1.5 h and the achieves the stable state or keeps slowly increasing. The third type is similar to the second one, when the maximal VOC level is achieved after 1.5 h but then a slow fall of concentration occurs. This is a typical in case paints, which can be explained because at the first moment the paints are rapidly drying and therefore releasing large amount of VOCs, but after the initial process the drying slows down and some of the VOCs settle on the surface of the room.

It is relatively difficult to compare the obtained results with other authors works due to the specifics of used materials and how the emitted VOCs can vary depending on the source. Also, the measuring devices, their working principle and experimental setup varies between the authors. However, if comparing the results how VOC concentration changes in ventilated chamber if solvent-based paint is introduced into it with the results presented by previous paper [19] then it can be noted that the VOC change dynamic is quite similar. By knowing that in other experiment the ventilation rate was nine exchange rate per hour while in our experiment only one, then the expected results would be even more comparable as the VOC level would decrease in shorter time period.

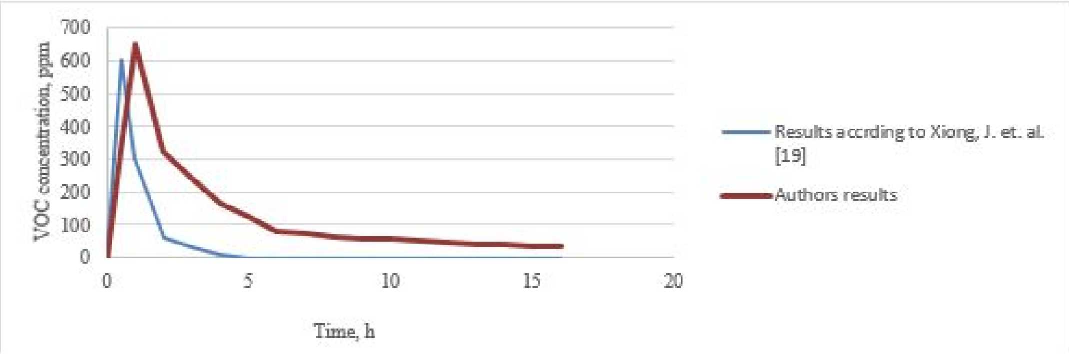

Figure 8. Comparison of authors and other researchers results of VOC concentration change in ventilated test chamber caused by solvent-based paint.

For future experiments additional tests should be made where the same pollution source is introduced in the room in various amounts to determine the relation between the pollution amount, the measured VOC level and room volume. Also, different types of the same pollution sources should be analyzed to determine weather they differ and for some of the sources full analysis of the actual compounds that make up the total VOC concentration should be specified.

4. Conclusions

During the experiment following VOC pollution sources were tested in a closed climatic chamber-sprayable window cleaner, aroma candles, sprayable air refresher, waterborne acryl-based paint, solvent based paint and acrylic based hermetic sealant. The results showed that for each pollutant type the VOC level differs depending on the content and amount of the pollutant, but in all cases the pollution level exceeded the threshold limit which is not harmful for human health.

By testing different amounts of sprayable window cleaner it was concluded that by doubling the pollution source the measured VOC level is not doubled but increases only by 50 %.

Three different types VOC concentration increase profiles were determined - rapid increase, slow release and slow release with small backdrop of VOC concentration. This is dependent on the type of pollution source, weather it is directly deployed in the air as an aerosol or laid on the surface.

In case the chamber is ventilated with an air exchange rate according to local regulations of 3 $m^3/h/m^2$ the maximum concentration of VOC is reached approximately at the same time as in unvented chamber, but the maximal concentration is lower by 33 % than in an unventilated room. However, the study confirms that if a room is ventilated according to the local Latvian building code LBN 211-15 the premise will be fully ventilated and harmless for people health only after 15–20 h after the introduction of the pollution source.

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References

1. Uhde, E., Salthammer, T. Impact of reaction products from building materials and furnishings on indoor air quality-A review of recent advances in indoor chemistry. Atmospheric Environment. 2007. No. 41 (15). Pp. 3111–3128. DOI: 10.1016/j.atmosenv.2006.05.082.
2. Sarigiannis, D.A., Karakitsios, S.P., Gotti, A., Liakos, I.L., Exposure to major volatile organic compounds and carbonyls in European indoor environments and associated health risk. Environment International, 2011. No. 37 (4). Pp. 743–765. DOI: 10.1016/j.envint.2011.01.005.
3. Dimitroulopoulou, C. Ventilation in European dwellings: A review. Building and Environment. 2012. No. 47 (1). Pp. 109–125. DOI: 10.1016/j.buildenv.2011.07.016.

Литература

1. Uhde E., Salthammer T. Impact of reaction products from building materials and furnishings on indoor air quality-A review of recent advances in indoor chemistry // Atmospheric Environment. 2007. № 41(15). Pp. 3111–3128. DOI: 10.1016/j.atmosenv.2006.05.082.
2. Sarigiannis D.A., Karakitsios S.P., Gotti A., Liakos I.L., Exposure to major volatile organic compounds and carbonyls in European indoor environments and associated health risk // Environment International, 2011. № 37(4). Pp. 743–765. DOI: 10.1016/j.envint.2011.01.005.
3. Dimitroulopoulou C. Ventilation in European dwellings: A review // Building and Environment. 2012. № 47(1). Pp. 109–125. DOI: 10.1016/j.buildenv.2011.07.016.

4. Kim, YM., Harrad, S., Harrison, RM. Concentrations and sources of VOCs in urban domestic and public microenvironments. Environmental Science & Technology. 2001. Vol. 35. Pp. 997–1004. DOI: 10.1021/es000192y.
5. WHO. 1989. World Health Organization. Indoor air quality: organic pollutants. Copenhagen: WHO Regional Office for Europe; EURO Report and Studies 1111.
6. Gorshkov, A.S., Vatin, N.I., Rymkevich, P.P., Kydrevich, O.O. Payback period of investments in energy saving. Magazine of Civil Engineering. 2018. 68(2). Pp. 65–75. DOI: 10.18720/MCE.78.5.
7. Borodinecs, A., Zemitis, J., Sorokins, J., Baranova, D.V., Sovetnikov, D.O. Renovation need for apartment buildings in Latvia. Magazine of Civil Engineering. 2016. 68(8). Pp. 58–64. DOI: 10.5862/MCE.68.6
8. Kaunelienė, V., Prasauskas, T., Krugly E., Stasiulaitienė I., et al. Indoor air quality in low energy residential buildings in Lithuania, Building and Environment. 2006. Vol. 108. Pp 63–72. DOI: 10.1016/j.buildenv.2016.08.018.
9. Jiang, C., Li, D., Zhang, P., Li, J., et al. Formaldehyde and volatile organic compound (VOC) emissions from particleboard: Identification of odorous compounds and effects of heat treatment. Building and Environment. 2017. Vol. 117. Pp. 118–126. DOI: 10.7764/RDLC.16.3.527.
10. Aydin, I., Colakoglu, G., Colak, S., Demirkir, C. Effects of moisture content on formaldehyde emission and mechanical properties of plywood. Building and Environment. 2006. Vol. 41. No. 10. Pp. 1311–1316. DOI: 10.1016/j.buildenv.2005.05.011
11. Bilous, I.Yu., Deshko, V.I., Sukhodub, I.O. Building inside air temperature parametric study. Magazine of Civil Engineering. 2016. 68(8). Pp. 65–75. DOI: 10.5862/MCE.68.7.
12. Seung-Ho, S. Wan-Kuen, J. Volatile organic compound concentrations in newly built apartment buildings during pre- and post-occupancy stages. International Journal of Environmental Analytical Chemistry. 2013. Vol. 94. Pp. 356–369. DOI: 10.1080/03067319.2013.814125.
13. Berglund, B., Clausen, G., De Ceaurriz, J., Ketrrup, A., Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations. Report No 19. Luxemburg: Indoor Air Quality Investigations, 1997. Pp. 48. DOI: http://www.inive.org/medias/ECA/ECA_Report19.pdf
14. Rahman, M.M., Kim, K.H. Potential hazard of volatile organic compounds contained in household spray products. Atmospheric Environment. 2014. Vol. 85. Pp. 266–274. DOI: 10.1016/j.atmosenv.2013.12.001.
15. Ahn, J., Kim, K., Kim, Y., Kim, B. Characterization of hazardous and odorous volatiles emitted from scented candles before lighting and when lit. Journal of Hazardous Materials. 2015. Vol. 286. Pp. 242–251. DOI: http://dx.DOI.org/10.1016/j.jhazmat.2014.12.040.
16. Pukhkal, V., Vatin, N., Murgul, V. Central Ventilation System with Heat Recovery as One of the Measures to Upgrade Energy Efficiency of Historic Buildings. Applied Mechanics and Materials. 2014. Vols. 633-634. Pp. 1077–1081. DOI: 10.4028/www.scientific.net/AMM.633-634.1077.
17. Murgul, V., Vuksanovic, D., Vatin, N., Pukhkal, V. The Use of Decentralized Ventilation Systems with Heat Recovery in the Historical Buildings of St. Petersburg. Applied Mechanics and Materials. 2014. Vols. 635-637. Pp. 370–376. DOI: 10.4028/www.scientific.net/AMM.635-637.370.
18. Dinh, T.V., Kim, SY., Son, YS. et al. Emission characteristics of VOCs emitted from consumer and commercial products and their ozone formation potential. Environmental Science and Pollution Research. 2015. Vol. 22. Pp. 9345–9355. DOI: 10.1007/s11356-015-4092-8
19. Xiong, J., Wang, L., Bai, Y., Zhang, Y. Measuring the characteristic parameters of VOC emission from paints.

4. Kim YM., Harrad S., Harrison RM. Concentrations and sources of VOCs in urban domestic and public microenvironments // Environmental Science & Technology. 2001. Vol. 35. Pp. 997–1004. DOI: 10.1021/es000192y.
5. WHO. 1989. World Health Organization. Indoor air quality: organic pollutants. Copenhagen: WHO Regional Office for Europe; EURO Report and Studies 1111.
6. Горшков А.С., Ватин Н.И., Рымкевич П.П., Кудревич О.О. Период возврата инвестиций в энергосбережение // Инженерно-строительный журнал. 2018. № 2(78). С. 65–75. DOI: 10.18720/MCE.78.5.
7. Бородинец А., Земитис Ю., Сорокинс Ю., Баранова Д.В., Советников Д.О. Необходимость реновации жилых зданий в Латвии // Инженерно-строительный журнал. 2016. № 8(68). С. 58–64. DOI: 10.5862/MCE.68.6
8. Kaunelienė V., Prasauskas T., Krugly E., Stasiulaitienė I., et al. Indoor air quality in low energy residential buildings in Lithuania // Building and Environment. 2006. Vol. 108. Pp 63–72. DOI: 10.1016/j.buildenv.2016.08.018.
9. Jiang C., Li D., Zhang P., Li J., et al. Formaldehyde and volatile organic compound (VOC) emissions from particleboard: Identification of odorous compounds and effects of heat treatment // Building and Environment. 2017. Vol. 117. Pp. 118–126. ISSN 0360-1323, Available from DOI: 10.7764/RDLC.16.3.527.
10. Aydin I., Colakoglu G., Colak S., Demirkir C. Effects of moisture content on formaldehyde emission and mechanical properties of plywood // Building and Environment. 2006. Vol. 41. № 10. Pp. 1311–1316. DOI: 10.1016/j.buildenv.2005.05.011
11. Белоус И.Ю., Дешко В.И., Сухогуб И.О. Параметрический анализ внутренней температуры воздуха здания // Инженерно-строительный журнал. 2016. № 8(68). С. 65–75. DOI: 10.5862/MCE.68.7.
12. Seung-Ho S. Wan-Kuen J. Volatile organic compound concentrations in newly built apartment buildings during pre- and post-occupancy stages // International Journal of Environmental Analytical Chemistry. 2013. Vol. 94. Pp. 356–369. DOI: 10.1080/03067319.2013.814125.
13. Berglund B., Clausen G., De Ceaurriz J., Ketrrup A., Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations. Report No 19. Luxemburg: Indoor Air Quality Investigations, 1997. Pp. 48. DOI: http://www.inive.org/medias/ECA/ECA_Report19.pdf
14. Rahman M.M., Kim K.H. Potential hazard of volatile organic compounds contained in household spray products. Atmospheric Environment. 2014. Vol. 85. Pp. 266–274. DOI: 10.1016/j.atmosenv.2013.12.001.
15. Ahn J., Kim K., Kim Y., Kim B. Characterization of hazardous and odorous volatiles emitted from scented candles before lighting and when lit // Journal of Hazardous Materials. 2015. Vol. 286. Elsevier. Pp. 242–251. DOI: http://dx.DOI.org/10.1016/j.jhazmat.2014.12.040.
16. Pukhkal V., Vatin N., Murgul V. Central Ventilation System with Heat Recovery as One of the Measures to Upgrade Energy Efficiency of Historic Buildings // Applied Mechanics and Materials. 2014. Vols. 633-634. Pp. 1077–1081. DOI: 10.4028/www.scientific.net/AMM.633-634.1077.
17. Murgul V., Vuksanovic D., Vatin N., Pukhkal V. The Use of Decentralized Ventilation Systems with Heat Recovery in the Historical Buildings of St. Petersburg // Applied Mechanics and Materials. 2014. Vols. 635-637. Pp. 370–376. DOI: 10.4028/www.scientific.net/AMM.635-637.370.
18. Dinh T.V., Kim SY., Son YS. et al. Emission characteristics of VOCs emitted from consumer and commercial products and their ozone formation potential // Environmental Science and Pollution Research. 2015. Vol. 22. Pp. 9345–9355. Available from DOI: 10.1007/s11356-015-4092-8

Building and Environment. 2013. Vol. 66. Pp. 65–71. DOI: 10.1016/j.buildenv.2013.04.025.

20. Schieweck, A, Bock, M.C Emissions from low-VOC and zero-VOC paints – Valuable alternatives to conventional formulations also for use in sensitive environments? Building and Environment. 2015. Vol. 85. Pp. 243–252. DOI: 10.1016/j.buildenv.2014.12.001.
21. LBN 211-15: 2015. Dzivojamas ekas [Residential buildings]. Latvian building code.
22. OSHA. 2018. OSHA Occupational Chemical Database [online], [cited 5 June 2018]. Occupational Safety and Health Administration. Available from Internet: https://www.osha.gov/chemicaldata/
23. NIOSHA. 2018. NIOSHA The National Institute for Occupational Safety and Health [online], [cited 5 June 2018]. The National Institute for Occupational Safety and Health. Available from Internet: https://www.cdc.gov/niosh/index.htm
24. ACGIH. 2018. ACGIH Association Advancing Occupational and Environmental Health [online], [cited 5 June 2018]. Association Advancing Occupational and Environmental Health. Available from Internet: https://www.acgih.org/

19. Xiong J., Wang L., Bai Y., Zhang Y. Measuring the characteristic parameters of VOC emission from paints // Building and Environment. 2013. Vol. 66. Pp. 65–71. ISSN: 03601323. Available from DOI: 10.1016/j.buildenv.2013.04.025.
20. Schieweck A, Bock M.C Emissions from low-VOC and zero-VOC paints – Valuable alternatives to conventional formulations also for use in sensitive environments? // Building and Environment. 2015. Vol. 85. Pp. 243–252. DOI: 10.1016/j.buildenv.2014.12.001.
21. LBN 211-15: 2015. Dzivojamas ekas [Residential buildings]. Latvian building code.
22. OSHA. 2018. OSHA Occupational Chemical Database [online], [cited 5 June 2018]. Occupational Safety and Health Administration. Available from Internet: https://www.osha.gov/chemicaldata/
23. NIOSHA. 2018. NIOSHA The National Institute for Occupational Safety and Health [online], [cited 5 June 2018]. The National Institute for Occupational Safety and Health. Available from Internet: https://www.cdc.gov/niosh/index.htm
24. ACGIH. 2018. ACGIH Association Advancing Occupational and Environmental Health [online], [cited 5 June 2018]. Association Advancing Occupational and Environmental Health. Available from Internet: https://www.acgih.org/

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