

Article

The Presence of Aromatic Substances in Incense: Determining Indoor Air Quality and Its Impact on Human Health

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Abstract: Indoor air quality has become a topic of great concern. Burning incense has recently been identified as one of the primary sources of volatile organic compounds, specifically benzene, in an indoor setting. The current paper aims to evaluate volatile organic compound (VOC) emissions, particularly benzene, within indoor environments through the utilization of an experimental clean room. Experimental findings showed that 10 types of incense sticks emitted benzene in concentrations between 11.1 and 66.5 $\mu\text{g m}^{-3}$, which were 2.5 lower than the limit suggested for non-occupation indoor exposure (160 $\mu\text{g m}^{-3}$), identified by the American Association of Industrial Hygienists (ACGIH). Furthermore, a correlation between the dimensions (diameter and length) of the combustible parts in an incense stick was investigated and indicated a slight influence on the release of benzene. Taking into consideration the substantial influence benzene has on human health, coupled with a lack of precise legislation regarding indoor air quality in residential settings, this research serves as an initial investigation into the noteworthy effects of burning incense in private and public indoor settings.

Keywords: benzene; aromatic substances; indoor air quality; human health; incense; VOC; human exposure



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1. Introduction

Burning incense is commonly used in many countries for worship, home fragrance [1], and work activities (i.e., spas and yoga studios) [2]. In the last decades, the scientific community has focused on the air quality in indoor environments, where burning incense is generally performed [1,2]. The emission of hazardous compounds, such as volatile organic compounds (VOCs), during the combustion of incense sticks, has been documented. For instance, a work by Lee et al. (2004) stated that benzene, toluene, ethylbenzene, *m*-, *p*-xylene, and *o*-xylene were emitted during the burning of incense sticks at concentrations of 650.3, 323.8, 151.7, 21.8, and 102.7 $\mu\text{g g}^{-1}$, respectively. Furthermore, the average concentration of VOCs emitted in the room test chamber (e.g., ethylbenzene, *m*-, *p*-xylene, styrene, and *o*-xylene) was significantly higher with incense combustion [3]. In poorly ventilated environments, the compounds emitted from incense reach significant concentrations of harmful chemical pollutants [4]. Scientific experiments have proven that nu-

merous VOCs (e.g., benzene, limonene, and α -pinene) are, in fact, produced by fragranced consumer products [5]—for instance, incense. A work by BEUC (i.e., Bureau européen des unions de consommateurs) determined a concentration of benzene emitted in the test room of $221 \mu\text{g m}^{-3}$ [6]. Likewise, Wang et al. (2007) reported an average emission of benzene in temples in Hong Kong of $115 \mu\text{g m}^{-3}$, which exceeds the standard value ($16.1 \mu\text{g m}^{-3}$) by almost 8 times [7]. A chamber experiment exhibited an emission of benzene of $18\text{--}117 \mu\text{g m}^{-3}$, due to the combustion of incense sticks [8]. Likewise, a concentration of benzene of more than $200 \mu\text{g m}^{-3}$ was released by incense during a chamber experiment [6,9]. However, a clear assessment of the effects on humans is challenging due to limited studies on exposure [8]. Finally, it should be underlined that the European standardization committee produced three different standards, including EN 1673 [10], EN 16739 [11], and EN 16740 [12].

Benzene, toluene, ethylbenzene, and xylene are VOCs of particular concern (Table 1). They are known as the BTEX groups (i.e., benzene, toluene, ethylbenzene, and xylene) and are significantly present in indoor air. Among them, benzene demands particular attention. Evidence from human exposure and animal studies has confirmed the carcinogenicity of benzene [13]. Epidemiological studies have, in fact, proven the correlation between exposure to benzene and the development of aplastic anemia and leukemia [14], especially in children [15]. Likewise, people exposed to toluene and xylenes showed several adverse effects; toluene exposure determines a decrease in luteinizing hormone (LH) and follicle-stimulating hormone (FSH), significantly increasing the risk of spontaneous abortion [16]. Evidence has also proven that indoor air is the main route of human exposure to VOCs. VOCs are, in fact, typically present in higher concentrations in indoor air than in outdoor air [17]. However, few studies have been conducted on the contribution of burning incense to human exposure to VOCs.

A search on Scopus database using the keywords “Incense AND VOCs AND indoor AND air” provided only 23 articles, underlining the need to carry out more in-depth analyses on this issue. Current scientific literature reported that emissions of VOCs in indoor environments are due to activities, such as smoking, cooking, the use of liquefied petroleum gas combustion, natural gas equipment and biomass heating [9,18], and burning incense [9].

Table 1. Physical and chemical characteristics of the VOCs in the BTEX group [19].

Chemical Compound	Formula	Molecular Mass (g mol^{-1})	Boiling Point ($^{\circ}\text{C}$)	Solubility in Water (g m^{-3} at 25°C)
Benzene	C_6H_6	78.11	80.1	1780
Toluene	C_7H_8	92.14	110.6	515
Ethylbenzene	C_8H_{10}	106.17	136.0	160
Xylenes (<i>o</i> -, <i>m</i> -, <i>p</i> -)	C_8H_{10}	106.17	139.0	185

The present paper aims to provide further data on the contribution of burning incense sticks on VOCs emission and to assess the impact of using incense in both a private and public (workplace) place, with reference to the threshold values suggested by international organizations (World Health Organization, WHO). The quantification of benzene concentrations produced by the combustion of incense sticks is necessary for an in-depth analysis of the indoor air quality during the use of incense.

2. Materials and Methods

The analyzed incense sticks were taken from unopened boxes of incense sticks. Each of the 10 boxes contained 6 packs of 20 incense sticks. For each of the ten fragrances considered for analysis, one box was taken. The ten fragrances chosen for the benzene emission analysis were the best-selling ones (i.e., Ylang Ylang #1, Vanilla #2, Lavender #3, Pine #4, Opium #5, Precious Lily#6, Cannabis #7, Patchouli #8, Antistress #9, and White Musk #10). Before the experiments, the main characteristics of each incense stick

were taken into account: mass values, the diameter, and the length of the combustible part of each incense stick were measured. The values reported in Table 2 are the average of three measurements performed on each sample.

Table 2. Physical characteristics, such as the diameter and length of the combustible part and diameter, weight, aroma, and the burning time of the tested incense sticks. * Burning times refer to the time required for the stick to burn completely.

Sample	Combustible Part Length (cm)	Combustible Part Diameter (cm)	Weight (g)	Aroma	Burning Time (min) *
#1	13.9 ± 0.01	2.97 ± 0.03	1.31 ± 0.27	Ylang Ylang (Floral)	25
#2	12.7 ± 0.02	3.01 ± 0.02	1.29 ± 0.25	Vanilla	25
#3	12.4 ± 0.01	3.24 ± 0.19	1.29 ± 0.27	Lavender	25
#4	13.7 ± 0.13	2.89 ± 0.12	1.28 ± 0.46	Pine	25
#5	12.8 ± 0.12	3.65 ± 0.03	1.31 ± 0.20	Opium	25
#6	22.7 ± 0.03	2.18 ± 0.03	1.22 ± 0.24	Lily (Moss and flowers)	35
#7	23.6 ± 0.11	3.01 ± 0.04	1.45 ± 0.32	Cannabis (Resin)	35
#8	25.7 ± 0.14	4.96 ± 0.17	1.50 ± 0.18	Patchouli	35
#9	23.8 ± 0.23	3.54 ± 0.12	1.40 ± 0.18	Anti-stress Honey	35
#10	25.7 ± 0.16	4.36 ± 0.14	1.48 ± 0.30	White Musk	35

2.1. Experiments

Experiments were conducted by following the protocol suggested by Werner and Settimo [11], although slightly modified. The experimental clean room possessed a door and two windows [20]. The air sampler was a chemical desorption VOCs sampler [21] with a RAD130 adsorbent cartridge. The cartridge consisted of a stainless-steel mesh tube (100 mesh, 60 mm length, and 5.8 mm diameter). The tube was filled with 530 mg of activated carbon (35–50 mesh). The cartridge was inserted into the diffusive component of the instrument. Tests were performed in a test room with a total volume of 85.8 m³. The test room was completely aired by opening the door and windows before each incense stick was burned. Hence, before the first incense stick burn, the background air samples were collected from the chamber to assess the background air quality. After closing the door and windows, the sampling equipment was placed on furniture 1 m away from the wall and the incense stick was placed on a special support about 1 m away from the floor. Then, the sampler and incense stick were placed approximately 1.5 m apart. Therefore, the first incense stick was lit, and the test room remain closed until the end of the experiment (less than 1 h for the incense stick to burn completely). Burning time for incense sticks, indicated on the packaging, ranged between 25 and 35 min. Therefore, to guarantee the total combustion of each incense stick, 1 h was the time selected for combustion.

Afterward, the door and windows (n = 2) were again opened for complete room ventilation (60 min) and an air sample was taken as a blank. The VOCs trapped in the adsorbent phase were, then, desorbed using an organic solvent for subsequent instrumental analysis.

2.2. Chemical Analysis

For chemical analysis, VOCs were previously desorbed from the activated carbon adsorbent phase using 2 mL of CS₂. GC-FID analyses were carried out by means of a gas chromatograph model 6850 coupled with a flame ionization detector (FID) (Agilent Technologies, Santa Clara, CA, USA). The separation was conducted using a capillary column (20 m × 0.18 mm, 0.1 mm). Helium (99.99%) was used as the gas carrier with a constant flow rate of 1 mL min^{−1}. A total of 1 µL of the solution was injected into the separation system in split mode. Initially, the temperature of the oven was 60 °C for 2 min, then it was increased to 240 °C for 3 min. The final temperature was of 250 °C, which was held for 4 min. Following this procedure, satisfactory limits of detection (LOD) and reproducibility and repeatability were achieved for carrying out such measurements. In particular, LODs ranging between 0.1 and 0.5 µg m^{−3}

(benzene $0.1 \mu\text{g m}^{-3}$; toluene $0.18 \mu\text{g m}^{-3}$; ethylbenzene $0.1 \mu\text{g m}^{-3}$; xylenes $0.2 \mu\text{g m}^{-3}$; 1,3,5-trimethylbenzene $0.35 \mu\text{g m}^{-3}$; 1,2,4-trimethylbenzene $0.46 \mu\text{g m}^{-3}$), whereas average reproducibility and repeatability were below 4% and 7%, respectively. Data processing and elaboration were carried out using the Clarity software v.2.6.3 (Data Apex 2007, Prague, Czech Republic).

3. Results

The organic compounds identified in the different types of incense sticks after total combustion in the test room are reported in Table 3.

Table 3. Detected concentrations of each VOC ($\mu\text{g m}^{-3}$) in the air and collected in the test room during the total combustion of the investigated incense sticks. * The term “xylenes” means the mixture of three isomeric compounds of benzene (i.e., ortho-xylene, meta-xylene, and para-xylene). “<LOD” indicates that the VOC concentrations were below the limits of detection¹: (LODs) values. For the incense stick type: see the text.

Incense	# Sticks/L	Benzene	Toluene	Ethylbenzene	Xylenes *	1,3,5-Trimethylbenzene	1,2,4-Trimethylbenzene
#1	2/58	19.8	3.4	<LOD	<LOD	7.3	6.1
#2	2/57	12.1	<LOD	<LOD	<LOD	<LOD	<LOD
#3	2/65	22.8	<LOD	<LOD	<LOD	<LOD	<LOD
#4	2/56	20.6	<LOD	<LOD	<LOD	<LOD	<LOD
#5	2/63	16.9	<LOD	<LOD	<LOD	<LOD	<LOD
#6	2/66	11.1	2.7	<LOD	<LOD	5.8	<LOD
#7	2/63	66.5	12.6	<LOD	<LOD	<LOD	<LOD
#8	2/64	62.5	12.6	3.0	3.5	<LOD	<LOD
#9	2/66	38.6	6.8	<LOD	<LOD	<LOD	<LOD
#10	2/58	54.2	6.2	<LOD	<LOD	<LOD	<LOD

¹ benzene $0.1 \mu\text{g m}^{-3}$; toluene $0.18 \mu\text{g m}^{-3}$; ethylbenzene $0.1 \mu\text{g m}^{-3}$; xylenes $0.2 \mu\text{g m}^{-3}$; 1,3,5-trimethylbenzene $0.35 \mu\text{g m}^{-3}$; 1,2,4-trimethylbenzene $0.46 \mu\text{g m}^{-3}$.

From Table 3, it emerged that benzene was emitted by all the tested incense sticks, at concentrations ranging between 11.1 and $66.5 \mu\text{g m}^{-3}$. Toluene was emitted from complete combustion in 6 out of 10 incense sticks, at concentrations between 2.7 and $12.6 \mu\text{g m}^{-3}$. 1,3,5-trimethylbenzene was emitted by only two incense sticks, while ethylbenzene, xylenes, and 1,2,4-trimethylbenzene were from only one incense stick.

From the total combustion of incense stick #1, 19.8, 3.4, 7.3, and $6.1 \mu\text{g m}^{-3}$ of benzene, toluene, 1,3,5-trimethylbenzene, and 1,2,4-trimethylbenzene were emitted, respectively. Incense stick #2 emitted only benzene ($12.1 \mu\text{g m}^{-3}$), as did incense sticks #3 ($22.8 \mu\text{g m}^{-3}$), #4 ($20.6 \mu\text{g m}^{-3}$), and #5 ($16.9 \mu\text{g m}^{-3}$). Incense sticks showed an emission of benzene, toluene, and 1,3,5-trimethylbenzene at concentrations of 11.1, 2.7, and $5.8 \mu\text{g m}^{-3}$, respectively. Incense sticks #7, #9, and #10 emitted benzene and toluene during total combustion at concentrations of 66.5 and $12.6 \mu\text{g m}^{-3}$, 38.6 and $6.8 \mu\text{g m}^{-3}$, and 54.2 and $6.2 \mu\text{g m}^{-3}$, respectively. Finally, incense stick #8 emitted benzene, toluene, ethylbenzene, and xylenes at concentrations of 62.5, 12.6, 3.0, and $3.5 \mu\text{g m}^{-3}$, respectively.

The background levels resulting from the analyses showed an average benzene background level of $5 \mu\text{g m}^{-3}$. The other studied VOCs were under the LODs values. The results of the blanks are reported in Table 4. The benzene and toluene values determined in the chamber experiment were experimentally subtracted from the blank values.

Table 4. Levels of toxic and/or harmful substances sampled directly from the combustion of each stick after total combustion.

Incense	Benzene	Toluene	Ethylbenzene	Xylenes	Styrene	1,3,5-Trimethylbenzene	1,2,4-Trimethylbenzene	Total	Benzene	Toluene	Ethylbenzene	Xylenes	Styrene	1,3,5-Trimethylbenzene	1,2,4-Trimethylbenzene	Total
	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	µg	µg	µg	µg	µg	µg	µg	µg
#1	333	99.7	11.6	17.4	20.9	<LOD	1.4	791	6658	1994	232.0	348.2	418.0	<LOD	28.2	15,820
#2	1285	110.2	17.8	18.8	27.4	<LOD	1.4	1865	25,704	2205	357.0	375.8	548.0	<LOD	28.4	37,300
#3	1063	180.7	18.4	77.9	44.1	5.8	26.5	4163	21,252	3614	368.0	1558	882.2	116.2	530.8	83,260
#4	838	397.5	35.4	156.1	46.5	6.9	28.9	5248	16,754	7950	708.0	3122	929.4	137.6	577.6	104,960
#5	633	132.4	18.6	23.6	34.0	<LOD	4.5	1917	12,666	2648	372.4	471.2	680.0	<LOD	90.6	37,340
#6	654	329.3	45.4	36.3	94.3	3.6	6.3	2175	13,074	6586	907.2	726.6	1887	71.2	125.4	43,500
#7	1521	400.1	51.0	90.6	89.0	6.1	11.9	7404	30,416	8002	1020	1813	1780	122.2	239.0	94,080
#8	1017	101.8	12.7	25.9	21.0	2.1	3.3	2008	20,350	2036	253.4	518.0	420.4	42.4	65.4	40,160
#9	559	207.3	44.2	29.6	79.5	3.5	2.6	1481	11,184	4146	884.8	593.0	1590	69.8	52.8	29,620
#10	755	177.9	37.6	44.4	60.5	3.6	4.6	1976	15,098	3558	752.0	887.2	1210	72.6	9106	39,520

As evidenced by Table 3, the incense stick that exhibited the greatest quantity of benzene emission was #7, with #8, #10, and #9 following in descending order. Additionally, #7, #8, #9, and #10 were the incense sticks that yielded the highest levels of toluene.

Furthermore, Table 4 expresses the levels as absolute µg of toxic and/or harmful substances sampled directly from the combustion of each stick after total combustion.

In this case, the analytical spectrum encompassed a wider range of compounds, barring 1,3,5-trimethylbenzene, which was only found in the Ylang Ylang, Vanilla, and Opium samples. All (semi-)volatile compounds were detectable in the diverse incense sticks. For example, the variety in incense #7 showed a level of benzene of 30,416 µg absolute (30.416 mg), which corresponded to a 354.5 µg m⁻³ of benzene being emitted into the experimental room. Dispersion/dilution effects and other behaviors (i.e., thermodynamic exchanges and mechanisms of action) mean that the level of benzene sampled in the indoor environment was significantly lower than that emitted.

4. Discussion

People exposed to VOCs can be seriously affected by several adverse effects (e.g., risk of reproductive problems, respiratory complications, immune suppression, and cancer) [4,15]. Therefore, the identification of the sources of VOCs in indoor environments (not only temples) as well as the assessment of their concentration is of great interest to the scientific community. It is worth underlining that indoor environments (public and private) have a wide range of VOC sources, including the production and furnishing materials and cleaning products [20]. In private (and public) environments, another source of VOCs (in particular benzene) is the disc and liquid mosquito-repellent incense. Benzene accounted for the largest proportion of VOCs emitted by disc and liquid mosquito-repellent incenses, with concentrations of 190 µg m⁻³ and 130 µg m⁻³, respectively [21].

4.1. Impact of Dimensions on Benzene Emissions

Scientific evidence has reported that the dimensions of the incense stick can affect the level of pollution generated [2]. Silva et al. (2021) stated that the size of the incense sticks might influence the level of VOCs being emitted, although it was not linear [2]. In the present paper, the benzene concentrations being emitted from the sticks two hours after combustion were related to both the length and diameter of the combustible part; thus, an in-depth investigation into whether the dimensions can affect the benzene emitted was conducted.

To this purpose, only benzene was considered as it was the only VOC emitted by all the tested sticks. The length showed a correlation value with the emitted benzene of 0.76. Basically, this value indicates a good positive correlation. However, the graph shows (Figure 1a) that the increased concentration of benzene emitted does not increase as the length of the fuel part of the rod increases for all sticks. The correlation between the diameter of the fuel part and the emitted benzene levels was 0.69 (Figure 1b). In

this case, there was no correlation between the size and the levels of benzene emitted. However, the value indicates a slight tendency for sticks with a larger diameter to emit higher levels of benzene.

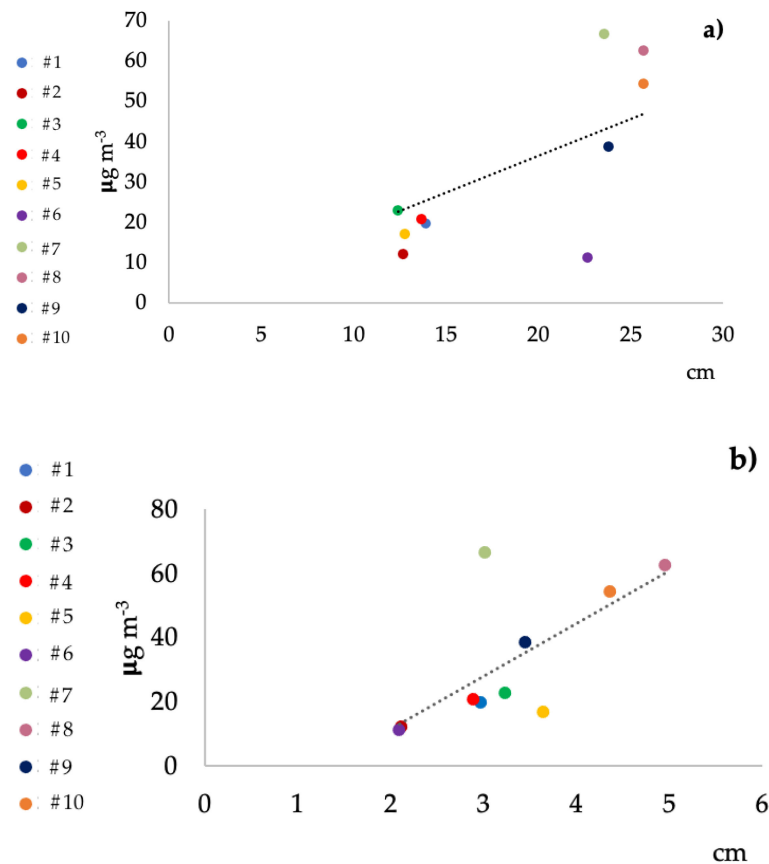


Figure 1. (a) Graph of the correlation between the length (cm) of the combustible part of the incense stick and the emitted concentration of benzene ($\mu\text{g m}^{-3}$); (b) graph of the correlation between the diameter (cm) of the combustible part of the incense stick and the emitted concentration of benzene ($\mu\text{g m}^{-3}$).

Therefore, our results suggest an impact of the length of the combustible part on the levels of benzene emitted, even if they are not valid for all the sticks, with the same sampling time and in the absence of other variables that can influence the burning (e.g., ventilation of the environment). Likewise, a slight influence by the diameter might be suggested [2].

4.2. Human Exposure to Benzene

Humans exposed to benzene can present serious negative effects. For instance, benzene exposure reduces the abundance of immune cells in multiple immune organs, such as bone marrow, thymus, spleen, and liver [22]. Furthermore, exposure during in utero fetal development can cause fetal abnormalities [23]. Therefore, exposure to benzene, in both private and public environments, should be investigated in-depth. In the present study, 8 out of the 10 incense sticks tested resulted in the emission of benzene exceeding $17 \mu\text{g m}^{-3}$, which is the guideline value presented by the World Health Organization (WHO) [1] (Figure 2).

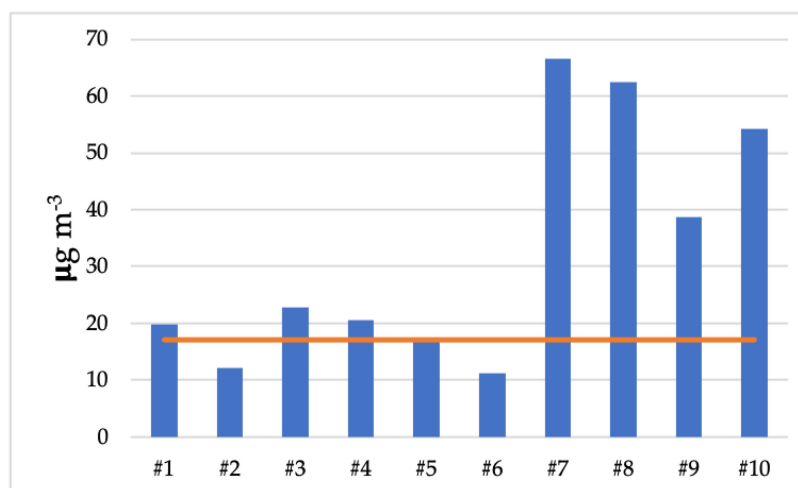


Figure 2. Concentrations of benzene emitted by the tested incense sticks. The orange line indicates the limit value of benzene suggested by WHO.

The European Union currently abides by WHO guidelines for air quality, which are centered on assessing health and hygiene implications. These guidelines utilize an evaluation of acceptable risk levels in consideration of all relevant scientific evidence and establish concentration thresholds below which lifetime exposure (or exposure for a specific time frame) is considered safe for human health. Precisely, the guideline by WHO for carcinogenic substances established a concentration of $17 \mu\text{g m}^{-3}$ for exposures throughout the life span and throughout the working life, without suffering harmful health effects [24].

In Italy, as well, no specific regulation on residential indoor air quality is currently in force [25–27]. On the contrary, in Italy, levels of workplace exposure to carcinogens and mutagenic agents have been established in Legislative Decree No. 81/2008, which aims at the protection of health and safety at work. TLV-TWA, established by Legislative Decree No. 81/2008, is $3.25 \mu\text{g m}^{-3}$. However, Legislative Decree No. 81/2008 is not applicable to residential environments [28]. Furthermore, since 1938, the American Association of Industrial Hygienists (ACGIH) has focused on health in the workplace. Annually, the ACGIH publishes the Threshold Limit Value (TLV) for workplace exposure to benzene (1.6 mg m^{-3} for an 8-h exposure). The relative non-occupational indoor exposure is ((TLV-TWA)/10), namely, $1.6/10$ is equal to $160 \mu\text{g m}^{-3}$. The values determined in the present study, using different varieties of incense, are 2.5 times lower (considering the upper extreme value of $66.5 \mu\text{g m}^{-3}$, recorded by stick #7 variety).

The key factor in ensuring proper exposure assessment is to consider the environment in question, the methodology for incense stick use, and the relevant exposure references, as the reference limit for exposure is identified for an 8 h workday, while the value discovered pertains to a single incense stick's combustion (approximately 40 min) and may require normalization. Furthermore, over the last couple of decades, the European Union has importantly focused on air quality in indoor environments. For instance, the European project INDEX (Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU) has aimed to assess indoor limit values [29,30]. The study identified formaldehyde, nitrogen dioxide, carbon monoxide, benzene, and naphthalene as priority pollutants for European regulation, suggesting exposure limits, recommendations, and control measures to minimize health risks. The publication of those guidelines ended the use of risk assessments for Occupational Exposure Limit Values (OELVs) or TLVs proposed by the ACGIH, which were reduced by 1/10 or 1/100, respectively.

It is notable that the World Health Organization reaffirmed this guidance in the early 1980s through the publication of "Indoor Air Pollutants: Exposure and Health Effects". The document highlighted the unsuitability of industrial occupational exposure limit values for non-industrial indoor environments. Thus, there was a need to establish specific refer-

ences for residential indoor environments to effectively address the health risks associated with indoor air pollution [30]. For instance, guide values (GVs) for residential indoor environments have been proposed by several research groups. However, the GV might differ for the same compound depending on the country. This is mainly due to the use of different pathways when drafting the GV. The simple development of the GV has led to an improvement in indoor air quality. Unlike the present limit values for indoor air quality, GV's have the advantage, whereby their use could lead to measures being taken, even when concentrations are below the established GV [31]. Furthermore, particular attention should be given to the most vulnerable groups, as specified by the European Commission's Scientific Committee on Health and Environmental Risks (SCHER). The SCHER has, in fact, suggested a case-by-case approach for assessing the GV's to protect vulnerable people (i.e., children, pregnant women, and the elderly (over 65) people suffering from asthma and other respiratory diseases, and cardiovascular diseases). Furthermore, genetic characteristics, nutritional status, and lifestyles can all contribute to a more vulnerable population. Additionally, it should be noted that certain ethnic groups, who have established permanent settlements within various national territories, frequently and extensively, utilize incense within their domestic spaces [8]. However, in Europe, only a few Community-member countries, such as France, the Netherlands, the United Kingdom, Belgium/Flemish Region, Portugal, and Poland (which even differentiates between residential indoor and indoor public offices), have provided guideline values, included in their body of legislation (e.g., France: law No. 2010-788 from 12 July 2010, National Environmental Commitment; Portugal: law No. 79-2006), where values vary between $2 \mu\text{g m}^{-3}$ and $10 \mu\text{g m}^{-3}$.

4.3. Human Exposure to Other VOCs

Exposure to toluene, ethylbenzene, and other VOCs is scarcely investigated in scientific literature. The WHO have also set values for toluene, ethylbenzene, xylenes, 1,3,5-trimethylbenzene and 1,2,4-trimethylbenzene [25]. On the other hand, no limits were found in the scientific literature for 1,3,5-trimethylbenzene and 1,2,4-trimethylbenzene. Therefore, although findings are relative to benzene for an exposure time of two hours, it is plausible to assume that the levels of the VOCs emitted by incense are well below the suggested threshold values.

Toluene and *o*-, *m*-, and *p*-xylenes are classified as non-carcinogenic for humans, yet their adverse effects are not underrated [32]. It has been reported that the concentrations of ethylbenzene, *m*-, *p*-xylenes, *o*-xylene, and toluene increased with incense combustion as benzene did. However, benzene and toluene are emitted in higher concentrations, confirmed by scientific evidence [33]. People exposed to toluene, *m*-, *p*-xylenes, *o*-xylene, and ethylbenzene can have adverse effects in both the short- and long-term. Effects can range from mild to severe, such as eye, nose, throat or skin irritation, narcosis, neurotoxicity, aplastic anemia, cardiovascular conditions, respiratory problems, and kidney or liver damage [33].

It is important to note that experimental testing has demonstrated that when an aeration condition is established in a space that guarantees 95% volatile organic compounds (VOCs) removal, the concentrations of VOCs released can be substantially decreased within approximately 2 h following the cessation of combustion [34]. Based on experimental evidence, the emission of VOCs from the burning of incense sticks has a reduced impact on health in a room with a ventilation condition [34]. As a result, considering the exposure value suggested by the WHO, eight incense sticks showed a VOC release above the suggested guidelines value after two hours.

In any case, it should be considered that some practices of high use, frequency and duration, presence of vulnerable populations, together with indoor characteristics, and layout (volume of rooms/spaces, air exchange rate, etc.) can lead to chronic exposures that exceed the guideline or reference values (WHO), which does suggest the need to limit this type of exposure.

5. Conclusions

This paper aimed to assess the emission of VOCs by burning incense sticks in indoor environments since the investigation into their contribution to lowering air quality remains limited. Experimental findings showed that the analyzed incense sticks emitted a concentration of benzene 2.5 times lower than the limit suggested for non-occupational indoor exposure.

Furthermore, the impact of incense sticks' size was investigated. It was found that there is a slight positive correlation between the length of the combustion part of the incense stick and the emitted levels of benzene. Therefore, an influence could be suggested. Human exposure to VOCs has a significant impact on human health, it is necessary to monitor the "least studied" sources of VOCs. Even though in this paper no qualitative description has been conducted, this work should be considered a preliminary study on the health implications related to the use of incense sticks for recreational activities.

Finally, it should be mentioned that there is no agreement among researchers on the existence of a threshold dose for carcinogens and even more so on the possibility of its unambiguous determination. This issue has been largely discussed among scientists for many years [35]: consequently, for many it is not permissible to establish an exposure limit value, that is, to define an "acceptable" level of risk owing to the pathology that may possibly arise, although unlikely, it is always of the same severity and not dependent on the intensity and duration of the exposure. For all these reasons, further studies are needed to confirm these suggested hypotheses.

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