

Indoor Air Quality Assessment During the Use of Tobacco and Nicotine Products *

by

Peter J. Wilkinson¹, Anna Clarke¹, Ian M. Fearon², and Ronan Barry¹

¹ Advanced Inhalation Rituals (AIR) Group Ventures, Festival Office Tower, Dubai Festival City, Dubai, UAE

² whatIF? Consulting Ltd, Harwell, UK

SUMMARY

Chemical toxicants released into the environment during the use of tobacco and nicotine products potentially give rise to an elevated health risk among non-users. The aim of this study was to assess the levels of a wide range of chemical toxicants in the indoor air of an unventilated testing facility during various scenarios of tobacco and nicotine product use, including the use of conventional waterpipes, electronic vaping products (EVPs, also known as e-cigarettes), an electronic waterpipe which uses electrical heating of shisha tobacco instead of conventional charcoal heating, and combustible-cigarettes. In the one-occupant scenarios, increases in PM₁₀ and PM_{2.5} were greatest during conventional waterpipe use, approximately 40% lower for OOKA electronic waterpipe use, and lowest for EVP use. An increase in the combustion by-product CO was greatest for conventional waterpipe use, and substantially lower for EVP and OOKA electronic waterpipe use, with the latter generating only a negligible amount of CO. The increase in formaldehyde levels was greatest for conventional waterpipe use, and substantially lower for OOKA electronic waterpipe use. In ten-occupant product use scenarios, increases in PM₁₀ and PM_{2.5} were greatest for EVP use and slightly lower for OOKA electronic waterpipe use, lower during the cigarette smoking scenario, and lowest for the unattended conventional waterpipes

scenario. Increases in CO and formaldehyde were highest for the conventional waterpipes scenario, substantially lower during cigarette smoking, and negligible for OOKA electronic waterpipe and EVP use. Increases in several other volatile organic compounds and some polycyclic aromatic hydrocarbons were mainly seen only during cigarette smoking and were negligible during the other product use scenarios. This pattern was similar for the tobacco-specific nitrosamines NNN, NNK, and NAT. These findings have important implications concerning the potential for secondhand toxicant exposure among waterpipe non-users, and for understanding how to potentially reduce health risks associated with such exposure. [Contrib. Tob. Nicotine Res. 34 (2025) 230–241]

KEYWORDS

Waterpipe; emissions; indoor air quality; electronic vaping product; cigarettes

ZUSAMMENFASSUNG

Chemische Giftstoffe, die beim Konsum von Tabak und Nikotinprodukten in die Umwelt freigesetzt werden, bergen möglicherweise ein erhöhtes Gesundheitsrisiko für Nicht-

*Received: 17th June 2025 – accepted: 28th November 2025

konsumenten. Ziel dieser Studie war es, die Konzentrationen einer breiten Palette chemischer Giftstoffe in der Raumluft einer unbelüfteten Testeinrichtung während verschiedener Szenarien des Konsums von Tabak und Nikotinprodukten zu ermitteln, darunter die Verwendung herkömmlicher Wasserpfeifen, elektronischer Vaping Produkte (EVPs, auch als E-Zigaretten bekannt), elektronischer Wasserpfeifen, bei denen Shisha-Tabak elektrisch statt mit herkömmlicher Holzkohle erhitzt wird, und brennbarer Zigaretten. Bei Szenarien mit einem Konsumenten waren die Anstiege von PM10 und PM2.5 bei der Verwendung herkömmlicher Wasserpfeifen am höchsten, bei der Verwendung elektronischer OOKA Wasserpfeifen um etwa 40% niedriger und bei der Verwendung von EVPs am niedrigsten. Der Anstieg des Verbrenungsnebenprodukts CO war bei der Nutzung konventioneller Wasserpfeifen am stärksten, bei der Nutzung von EVP deutlich schwächer, bei Verwendung von OOKA Wasserpfeifen wurde nur eine vernachlässigbare Menge CO erzeugt. Der Anstieg der Formaldehydwerte war bei konventionellen Wasserpfeifen am stärksten und bei OOKA deutlich geringer. In Zehn-Personen-Szenarien zur Produktnutzung waren die Anstiege der PM10- und PM2.5-Werte bei EVP am stärksten, bei OOKA etwas geringer, beim Zigarettenrauchen geringer und beim unbeaufsichtigten Szenario konventioneller Wasserpfeifen am geringsten. Die Anstiege von CO und Formaldehyd waren bei konventionellen Wasserpfeifen am stärksten, beim Zigarettenrauchen deutlich geringer und bei OOKA und EVP vernachlässigbar. Anstiege mehrerer anderer flüchtiger organischer Verbindungen und einiger polyzyklischer aromatischer Kohlenwasserstoffe wurden hauptsächlich beim Zigarettenrauchen beobachtet und waren bei den anderen Produktnutzungsszenarien vernachlässigbar. Dieses Muster war für die tabakspezifischen Nitrosamine NNN, NNK und NAT ähnlich. Diese Erkenntnisse haben wichtige Auswirkungen auf das Risiko einer Passivrauchbelastung von Personen, die selbst keine Wasserpfeifen rauchen, und auf das Verständnis darüber, wie sich die mit einer solchen Belastung verbundenen Gesundheitsrisiken möglicherweise verringern lassen. [Contrib. Tob. Nicotine Res. 34 (2025) 230–241]

RESUME

Les substances chimiques toxiques libérées dans l'environnement lors de la consommation de produits à base de tabac et de nicotine peuvent entraîner un risque accru pour la santé des non-consommateurs. L'objectif de cette étude était d'évaluer les niveaux d'un large éventail de substances chimiques toxiques dans l'air intérieur d'un centre d'essai non ventilé lors de divers scénarios de consommation de produits à base de tabac et de nicotine, notamment l'utilisation de pipes à eau conventionnelles, de produits de vapotage électroniques (EVP, également appelés cigarettes électroniques), d'une pipe à eau électronique utilisant le chauffage électrique du tabac à chicha au lieu du chauffage au charbon de bois traditionnel, et de cigarettes combustibles. Lors de scénarios impliquant un seul occupant, les augmentations de PM10 et PM2.5 étaient les plus importantes lors de l'utilisation de pipes à

eau conventionnelles, environ 40% inférieures pour l'utilisation de pipes à eau électroniques OOKA et les plus faibles pour l'utilisation de EVP. L'augmentation du monoxyde de carbone (CO) par combustion était la plus importante pour l'utilisation de pipes à eau conventionnelles, et nettement inférieure pour l'utilisation de EVP et de pipes à eau électroniques OOKA, ces dernières ne générant qu'une quantité négligeable de CO. L'augmentation des niveaux de formaldéhyde était la plus importante pour l'utilisation de pipes à eau conventionnelles, et nettement inférieure pour l'utilisation de pipes à eau électroniques OOKA. Dans dix scénarios d'utilisation de produits par les occupants, les augmentations de PM10 et PM2.5 étaient les plus importantes pour l'utilisation de l'EVP et légèrement inférieures pour l'utilisation de la pipe à eau électronique OOKA, plus faibles pendant le scénario de tabagisme et les plus faibles pour le scénario de pipes à eau conventionnelles sans surveillance. Les augmentations de CO et de formaldéhyde étaient les plus élevées pour le scénario de pipes à eau conventionnelles, nettement plus faibles pendant le tabagisme et négligeables pour l'utilisation de la pipe à eau électronique OOKA et de l'EVP. Les augmentations de plusieurs autres composés organiques volatils et de certains hydrocarbures aromatiques polycycliques ont été principalement observées uniquement pendant le tabagisme et étaient négligeables pendant les autres scénarios d'utilisation de produits. Cette tendance était similaire pour les nitrosamines NNN, NNK et NAT spécifiques au tabac. Ces résultats ont des implications importantes concernant le potentiel d'exposition aux toxiques secondaires chez les non-utilisateurs de pipes à eau et pour comprendre comment réduire potentiellement les risques pour la santé associés à une telle exposition. [Contrib. Tob. Nicotine Res. 34 (2025) 230–241]

ABBREVIATIONS

CO: Carbon monoxide
 EVP: Electronic vaping product
 NAT: *N*'-nitrosoanatabine
 NNK: 4-(Methylnitrosamino)-1-(3-pyridyl)-1-butanone
 NNN: *N*'-nitrosonornicotine
 PAH: Polycyclic aromatic hydrocarbon
 PM: Particulate matter
 PM10: Particulate matter with a diameter of 10 µm or less
 PM2.5: Particulate matter with a diameter of 2.5 µm or less
 TSNA: Tobacco-specific nitrosamine
 VOC: Volatile organic compound

INTRODUCTION

Waterpipe smoking is a form of tobacco use which is most commonly found in Middle Eastern, Eastern Mediterranean, and Eastern European countries (1–3). Waterpipe use involves heating a mixture of tobacco, flavourings, glycerol, and sweeteners, which is termed “shisha”. Most commonly, the heat source for waterpipe use is smouldering charcoal briquettes derived from either wood or coconut, which when lit are placed on a layer of perforated aluminium foil covering the shisha mixture (4–5). The

waterpipe user then puffs on the mouthpiece of the waterpipe hose, drawing heated air over the charcoal and through the shisha. The resulting aerosol is bubbled through water before being inhaled by the user (4–8). Following inhalation, the waterpipe aerosol is exhaled into the ambient air by the user. Between puffs, the charcoal briquettes remain smouldering which also releases potential toxicants, which include benzo[*a*]pyrene, volatile aldehydes, and carbon monoxide (CO), into the air (9–10). While waterpipe use most commonly occurs outdoors, waterpipes are also used in indoor areas such as homes, restaurants, bars, and cafes, giving rise to the potential for passive exposure to chemical toxicants (9–12).

Determination of the reduced risk potential of novel tobacco and nicotine products requires a weight of evidence approach (13) using data from pre-clinical, clinical, and behavioural studies (13–17) which take into account potential impacts across three broad domains: exposure, individual risk, and population harm (18). One important factor to assess as part of a comprehensive overall risk assessment of a novel tobacco product is the potential for exposure to chemical toxicants among non-users, often termed secondhand exposure. Assessing the potential for such exposure among waterpipe non-users can contribute to determining an overall population level health impact assessment (18). A number of studies have assessed the levels of chemical toxicants in indoor air either in real-world environments (e.g., in restaurants, waterpipe lounges, or the homes of users) (19–21) or in simulated (laboratory) environments or testing chambers (9). Broadly speaking, these studies have reported the levels of various chemical toxicants in indoor air, including classes of chemicals such as polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), aldehydes, as well as particulate matter and carbon monoxide (CO) (12, 19). While full toxicological risk assessments using data from toxicant level analyses were not conducted in most of these studies, the levels reported do give rise to the potential for adverse health consequences among non-users, a limited number of studies have reported associations between exposure and health impacts (19). Given these findings, reducing the potential for secondhand exposure could reduce any population level harms associated with secondhand waterpipe exposure.

Given the potential link between secondhand exposure and risk, the aim of this study was to assess the levels of a wide range of chemical toxicants in the indoor air of an unventilated testing facility during various scenarios of tobacco and nicotine product use, including the use of conventional waterpipes, electronic vaping products (EVPs, also known as e-cigarettes), an electronic waterpipe which uses electrical heating of shisha tobacco instead of conventional charcoal heating, and combustible cigarettes. The chemical toxicants assessed include a number of those mandated for lowering in cigarette smoking by the World Health Organization study group on Tobacco Product Regulation (TobReg) (22), as well as some deemed by the United States (US) Food and Drug Administration (FDA) as Harmful and Potentially Harmful Constituents in Tobacco Products and Tobacco Smoke (23). This study addresses a call for more research into emissions from conventionally and electronically heated waterpipes (2) and provides much

needed information concerning the potential for toxicant exposure associated with secondhand exposure during waterpipe use and how the potential for such exposure may be mitigated.

MATERIALS AND METHODS

Study products

- *Electronic vapour products*

When testing indoor air during the use of an EVP in the one-occupant scenario, the participant used a Vuse ePod with “Golden Tobacco” flavour (British American Tobacco, London, UK). For the ten-occupant scenarios with the use of EVPs, individual participants were allowed to select an EVP to use from the following list: VGOD pod system EVPs with “*Mango Bomb*”, “*Purple Bomb*”, or “*Lush Ice*” flavours, Vape Bar EVPs with “*Ghost Pro Pina Colada*” or “*Angel Watermelon Ice*” flavours, or Found Mary EVPs with “*Watermelon Ice*”, “*Juicy Grape Berries*”, “*Mixed Berries*”, “*Mango Peach*”, or “*Strawberry Watermelon*” flavours (Torrance, CA, USA). All EVPs contained 20 mg/mL nicotine.

- *Cigarettes*

When testing indoor air during cigarette smoking, individual participants smoked cigarettes of their choosing from a list of brands representing those most popular in the United Arab Emirates (UAE). These brands, and their “tar”/nicotine/CO emissions yields, were as follows: Davidoff Gold Slim (5/0.5/3), Parliament Platinum (1/0.1/1), Parliament Silver Blue (3/0.3/3), Marlboro Gold (6/0.5/7), Marlboro Red (8/0.6/8), L&M Blue Label (6/0.5/7), Gauloises Blondes (4/0.4/6), Winston Silver (3/0.3/4), Winston Blue (5/0.4/6), and Gold Coast American Blend (8/0.6/8).

- *OOKA electronic waterpipe*

The OOKA waterpipe (Advanced Inhalation Rituals, Dubai, UAE) is a battery-powered electronic device which uses heat conduction to heat an aluminium pod containing shisha molasses. The OOKA device has a thin film heating element on the wall of a micro-oven (Supplementary Figure 1) which conducts heat into the OOKA pod. Sensors placed around the micro-oven allow the temperature to be accurately measured allowing the OOKA to rapidly modify the heat energy inside the pod to reduce accidental overheating associated with conventional charcoal heated waterpipes.

When testing indoor air during waterpipe use, the head of the waterpipe was prepared with coconut-derived charcoal (Coco Avana, Barsa, Lebanon; 3 pieces per head) which was separated from the shisha tobacco with pre-perforated aluminium foil (Coco Avana). The charcoal was lit outside of the testing facility and brought into the room once lit and the shisha head prepared. The shisha tobacco used was “Gum with Mint” (Al Fakher, Dubai, UAE). When testing indoor air during electronic waterpipe (“OOKA”) use, the participant in the one-occupant scenario used OOKA pods containing “Two Apples” flavour (Al Fakher) while in the ten-occupant scenario the participants used OOKA pods



Figure 1. Photographic image of the indoor air testing facility.

(Al Fakher) containing various flavours of each participants' own choosing (blueberry, 3 participants; lemon with mint, 3 participants; gum with mint 2 participants; and Two Apples, 2 participants).

Study participants

Participants were male and female employees of Advanced Inhalation Rituals, and were either current cigarette smokers, current shisha users, and/or current EVP users. Participants' ages were all between 35 and 45 years of age.

Indoor air testing facility

The room of the indoor air testing facility (Figure 1) was located within the Al Fakher tobacco factory (Ajman, UAE) FZE accommodation block. The floor area of the room was 20.68 m² with a total volume of 62.04 m³. The room was ventilated with a 2-ton air conditioning system which provided 670 cubic feet per minute (approximately 19 m³/min) of conditioned air at 24 °C. This was switched off during product testing but was used to refresh the air of the testing facility between product use scenarios (see next section). The testing room contained a solid wooden door and one window that faced into an internal corridor. The room was equipped with solid walls and a tiled floor and contained 10 vinyl-covered chairs and 3 wooden tables.

Study procedures

During all product use scenarios, the door and the window of the testing room remained closed. Additionally, the local exhaust ventilation (LEV) system within the room was

switched off in order to assess air quality under non-ventilated conditions. Between the product use scenarios, the door and window were opened, and the LEV system was operated to remove atmospheric contaminants prior to the next experimental day. The room was also cleaned with water at the end of each experimental day.

On each experimental day, levels of indoor air analytes and parameters were evaluated under two scenarios. In the first scenario (unoccupied baseline assessment) the testing room remained empty with no human presence to simulate a non-occupied environment. Subsequent scenarios on each experimental day lasted for 60 minutes and were one of either: one occupant present in the room refraining from the use of any tobacco or nicotine products during the testing period; ten occupants present in the room refraining from the use of any tobacco or nicotine products during the testing period; one occupant using the OOKA electronic waterpipe *ad libitum* during the testing period; ten occupants using the OOKA electronic waterpipe *ad libitum* during the testing period; one occupant using an EVP *ad libitum* during the testing period; ten occupants using EVPs *ad libitum* during the testing period; one occupant using a waterpipe *ad libitum* during the testing period; ten waterpipes in an unattended room, i.e., no participants were using the waterpipe (see below); or ten occupants smoking cigarettes of their usual brand *ad libitum* during the testing period.

For the ten-occupant waterpipe session, due to safety concerns because of the LEV being switched off, the scenario was run without occupants. The rationale for this was due to a concern that the level of CO in the ambient air could reach a level that would pose a risk to occupants. In this regard, in the UAE shisha venues are required to have

LEV as part of their licensing requirements. The scenario therefore consisted of the testing room containing ten waterpipes set up with coconut-derived charcoal (3 pieces per waterpipe) placed on aluminium foil covering the waterpipe head containing shisha tobacco. After 30 min, the spent charcoal was removed from the waterpipe head and replaced with fresh charcoal, and the spent charcoal was removed from the testing facility. It is believed that whilst the approach was representative of the impact ten conventional waterpipes have on the ambient air, it would likely underestimate the impact due to an absence of active “puffing”, i.e., as a consumer drawing air across the charcoal, which tends to increase combustion and therefore the release of combustion products.

- *Indoor air collection & analysis*

A summary of the analytical methods used can be found in [Supplementary Table 1](#). Included below are brief details of (where appropriate) each sampling, extraction, and analytical method.

- *Volatile organic compounds, formaldehyde, glycerol and ethylene glycol*

Volatile organic compounds (VOCs) were measured using an active sampling approach by pumping the air over sorbent material in tubes. Once sampled, the tubes were sent for subsequent analysis at a laboratory to determine the mass of compounds captured on the tubes. This analysis was performed by gas chromatography with flame ionisation detection (GC-FID) for VOCs and high performance liquid chromatography with UV detection (HPLC-UV) for formaldehyde. Different adsorbent material in the tube was chosen depending on the target analyte. 2,4-dinitrophenylhydrazine (DNPH) treated silica was used for formaldehyde, Tenax TA thermal desorption tubes for the VOCs, and XAD7 for glycerol and ethylene glycol. The volume of air passing over the tubes was controlled by connecting a pump, a constant pressure controller and a flow meter. Once laboratory analysis was complete, the mass of compound detected (typically in total µg) was divided by the volume of air sampled (in m³) to determine a concentration in µg/m³.

- *Common indoor air pollutants (CO, CO₂, NO₂ & O₃)*

These gases were measured using a direct calibrated electrochemical sensor instrument (non-dispersive infrared for CO and CO₂, and an electrochemical cell for NO₂ and O₃; both from Graywolf Sensing Solutions (Shelton, CT, USA); see [Supplementary Table 1](#)). This equipment provided continuous real-time measurement of these pollutants with readings recorded every minute during the testing period.

- *Polycyclic aromatic hydrocarbons*

The same approach as that described above for VOCs was used, except that polycyclic aromatic hydrocarbons (PAHs) were collected using XAD2 sorbent tubes. The tubes were then analysed using quadrupole gas chromatography flame ionisation detection (GC-FID).

- *Metals*

Metals in the air were captured by pumping the air over cellulose ester membrane filter papers which captured the metal particles. The filter papers were then sent to the laboratory for analysis. Metals were extracted in 10% nitric acid, which for mercury was spiked with 1 ppm of gold. The mass of metals was determined using inductively coupled plasma mass spectrometry (ICP-MS). The mass was converted to a concentration using the same principle as described for the VOCs.

- *Tobacco-specific nitrosamines*

The tobacco-specific nitrosamines (TSNAs) NNN (*N*'-nitrosonornicotine), NAT (*N*'-nitrosoanatabine), NAB (*N*-nitrosoanabasine), and NNK (4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone) in the air of the testing facility were captured by pumping the air over glass fibre filter papers. The filters were then sent to the laboratory for analysis by gas chromatography to determine the mass of each TSNA collected. Samples were extracted from the filter papers with methanol/ammonium acetate, followed by solid phase extraction clean up. Determination of TSNA levels was performed by liquid chromatography tandem mass spectrometry (LC-MS/MS) and quantification using isotope-labelled internal standards.

- *Particulates (PM₁₀ & PM_{2.5})*

Particulates (PM₁₀, particulate matter with a diameter of 10 µm or less, and PM_{2.5}, particulate matter with a diameter of 2.5 µm or less) were measured using a Graywolf Advance Sense Pro nephelometer (Graywolf Sensing Solutions). This device contains an optical sensor that uses light scattering to provide a continuous real-time measurement of airborne particle mass. The nephelometer was calibrated by Omega Measuring & Calibration Laboratory, LLC (Dubai, UAE; an ISO 17025 accredited laboratory) using a gas of known composition, whilst particle size was calibrated by comparing the values of size and number of particles of polydisperse. Air was continuously drawn through the nephelometer and passed through a laser beam, which allowed individual particles to be assessed and size fraction to be determined. It should be noted that this equipment is unable to distinguish between solid particles (i.e., those arising from combustion) and liquid droplets (i.e., those arising from aerosolization during the heating process for EVPs and the OOKA electronic waterpipe).

- *Temperature and humidity*

Temperature in the testing facility was measured using a K-type thermocouple (Graywolf Sensing Solutions). Humidity was measured using a hygrometer (Graywolf Sensing Solutions).

Data presentation

For the online instrumental techniques, the values reported represent the average of each of the 1 minute readings from the whole sampling period, i.e. a 1-hour average will be the mean of 60 readings. For captured analytes, the quantity reported by the laboratory was divided by the sampling volume of air.

Table 1. Levels of selected analytes in indoor air for the one occupant scenarios. Analytes shown are those assessed which were above the lower limit of quantification in at least one testing scenario. For full raw and baseline-adjusted data for all analytes, refer to [Supplementary Tables 2 and 4](#), respectively. Analytes in bold are those mandated for lowering in cigarette smoke in the World Health Organization Study Group on Tobacco Product Regulation (TobReg) proposal (22). Data for the unoccupied baseline and one occupant baseline measurements are raw data. For the scenarios in which one occupant was in the testing room using the OOKA electronic waterpipe, using an EVP, or smoking cigarettes, data were normalised to the baseline analyte levels when one occupant was in the testing room but refraining from the use of tobacco and nicotine products.

Analyte (units)	LLOQ	Baseline-adjusted				
		Unoccupied baseline	Baseline one occupant	One occupant OOKA	One occupant EVP	One occupant waterpipe
PM10 ($\mu\text{g}/\text{m}^3$)	NA	9.1	12.1	313.4	24.1	500.4
PM2.5 ($\mu\text{g}/\text{m}^3$)	NA	5.6	5.5	311.2	26.1	486.8
CO (ppm)	0.3	2.2	2.0	0.1	0.8	17.4
CO ₂ (ppm)	1	717.7	868.4	220.4	507.3	700.7
Formaldehyde ($\mu\text{g}/\text{m}^3$)	0.1	6.7	6.7	6.3	0.0	26.3
Glycerol (mg/m^3)	0.1	<0.1	<0.1	0.25	0.00	3.40
<i>Metals</i>						
Chromium ($\mu\text{g}/\text{m}^3$)	0.4	<0.4	0.6	0.1	0.1	0.2
Copper ($\mu\text{g}/\text{m}^3$)	0.4	<0.4	0.9	0.2	-0.1	0.4
Manganese ($\mu\text{g}/\text{m}^3$)	0.4	<0.4	0.6	0.2	-0.2	0.1
<i>VOCs</i>						
Dichloromethane ($\mu\text{g}/\text{m}^3$)	1.7	<1.7	3.0	2.3	0.3	5.3
Carbon disulphide ($\mu\text{g}/\text{m}^3$)	1.7	2.4	25.0	-20.0	-21.7	-11.0
Chloroform ($\mu\text{g}/\text{m}^3$)	0.83	<0.83	<0.83	7.5	0.0	0.0
Benzene ($\mu\text{g}/\text{m}^3$)	0.83	<0.83	<0.83	0.0	0.37	0.30
Toluene ($\mu\text{g}/\text{m}^3$)	0.83	2.2	3.7	1.3	4.6	6.3
Ethylbenzene ($\mu\text{g}/\text{m}^3$)	0.17	0.67	0.83	0.67	1.7	2.0
Styrene ($\mu\text{g}/\text{m}^3$)	0.83	2.9	2.5	0.3	-0.2	1.3
Naphthalene ($\mu\text{g}/\text{m}^3$)	0.51	6.3	5.3	4.7	10.7	10.7
<i>n</i> -Hexane ($\mu\text{g}/\text{m}^3$)	0.83	0.75	1.0	0.00	0.30	1.2
Isopropanol ($\mu\text{g}/\text{m}^3$)	1.7	2.5	1.8	0.2	6.5	9.2
Propylene glycol monomethyl ether ($\mu\text{g}/\text{m}^3$)	1.7	<1.7	9.5	33.5	-6.7	23.5
Xylene ($\mu\text{g}/\text{m}^3$)	0.51	2.9	3.0	3.1	7.8	8.8

Abbreviations:

EVP: Electronic vapour product
 LOQ: Limit of quantification
 NA: Not applicable
 NAB: *N*-nitrosoanabasine
 NAT: *N*-nitrosoanatabine
 NNK: 4-(Methylnitrosamino)-1-(3-pyridyl)-1-butanone

NNN: *N*-nitrosonornicotine
 PAH: Polycyclic aromatic hydrocarbon
 PM10: Particulate matter with a diameter of 10 μm or less
 PM2.5: Particulate matter with a diameter of 2.5 μm or less
 TSNA: Tobacco specific nitrosamine
 VOC: Volatile organic compound

RESULTS

Levels of selected analytes (i.e., those assessed which were above the lower limit of quantification (LLOQ) in at least one testing scenario) for the one-occupant and ten-occupant scenarios are presented in Tables 1 and 2, respectively. Full datasets for both scenarios and for all analytes parameters assessed, including both raw and baseline adjusted data, can be found in [Supplementary Tables 2–5](#). Additionally, photographic images of the testing facility at baseline and at the end of the 60-minute product use scenarios can be found in [Supplementary Figure 2](#). For the one-occupant scenarios, levels of some analytes (PM10, CO₂) were increased at baseline (one occupant in the room but not undertaking any product use) compared with the unoccupied baseline levels (Table 1 and [Supplementary Table 3](#)). In the one-occupant product use scenarios (OOKA electronic waterpipe use, EVP use, or conven-

tional waterpipe use), increases in analytes levels when adjusted for one-occupant baseline levels were observed for a number of analytes including PM10, PM2.5, CO (conventional waterpipe use only), CO₂, formaldehyde, glycerol, dichloromethane, benzene (EVP and conventional waterpipe use only), toluene, ethylbenzene, styrene, naphthalene, *n*-hexane, isopropanol, propylene glycol monomethyl ether, xylene, and naphthalene (EVP use only; Table 1). Some increases were seen above baseline for a small number of the metals assessed, though these increases were very small in magnitude (Table 1 and [Supplementary Table 4](#)). No increases above baseline were seen during any of the scenarios for the TSNA (Supplementary Table 4). Regarding between product differences in the one-occupant scenarios, increases in PM10 and PM2.5 above baseline were greatest during conventional waterpipe use, approximately 40% lower for OOKA electronic waterpipe use, and lowest for EVP use. The increase in the combustion

Table 2. Levels of selected analytes in indoor air for the ten occupant scenarios. Analytes shown are those assessed which were above the lower limit of quantification in at least one testing scenario. For full raw and baseline-adjusted data for all analytes, refer to [Supplementary Tables 3 and 5](#), respectively. Analytes in bold are those mandated for lowering in cigarette smoke in the World Health Organization Study Group on Tobacco Product Regulation (TobReg) proposal (22). Data for the unoccupied baseline and ten-occupant baseline measurements are raw data. For the scenarios in which ten occupants were in the testing room using the OOKA electronic waterpipe, using EVPs, or smoking cigarettes, data were normalised to the baseline analyte levels when ten occupants were in the testing room but refraining from the use of tobacco and nicotine products. Data for the ten unattended waterpipes scenario, in which no participants were in the testing room, were normalised to the analyte levels during the unoccupied baseline measurement.

Analyte/parameter (units)	LLOQ	Baseline-adjusted					
		Unoccupied baseline	Baseline ten occupants	Ten occupants OOKA	Ten occupants EVPs	Ten unattended waterpipes	Ten occupants cigarettes
PM10 (µg/m ³)	NA	9.1	31.6	826.2	920.5	78.8	499.2
PM2.5 (µg/m ³)	NA	5.6	8.3	803.5	886.8	78.8	497.6
CO (ppm)	0.3	2.2	2.2	1.2	0.2	160.0	25.8
CO ₂ (ppm)	1	717.7	2116.6	1480.7	225.7	3128.5	719.2
Formaldehyde (µg/m³)	0.1	6.7	20.0	7.0	-7.0	1293.3	140.0
Glycerol (mg/m ³)	0.1	<0.1	<0.1	5.1	7.0	10.9	1.2
<i>Metals</i>							
Copper (µg/m ³)	0.4	<0.4	1.1	-0.6	-0.1	7.6	0.1
Manganese (µg/m ³)	0.4	<0.4	0.8	-0.4	-0.3	0.0	5.2
<i>VOCs</i>							
Dichloromethane (µg/m ³)	1.7	<1.7	<1.7	0.0	0.0	0.1	1.1
Carbon disulphide (µg/m ³)	1.7	2.4	5.5	-2.5	114.5	3.8	9.5
Benzene (µg/m³)	0.83	<0.83	<0.83	0.47	0.00	46.2	129.2
Toluene (µg/m ³)	0.83	2.2	3.8	1.2	0.2	17.8	176.2
Ethylbenzene (µg/m ³)	0.17	0.67	1.0	0.50	0.00	1.1	27.0
Styrene (µg/m ³)	0.83	2.9	7.8	-5.6	-4.1	-0.1	25.2
Naphthalene (µg/m ³)	0.51	6.3	13.0	5.0	5.0	11.7	2.0
<i>n</i> -Hexane (µg/m ³)	0.83	0.75	1.3	-0.30	0.20	0.08	8.7
Isopropanol (µg/m ³)	1.7	2.5	3.0	0.7	0.5	4.0	7.0
Phenol (µg/m ³)	1.7	<1.7	<1.7	0.1	0.0	3.1	26.3
Propylene glycol monomethyl ether (µg/m ³)	1.7	<1.7	<1.7	5.5	3.0	0.0	0.0
Xylene (µg/m ³)	0.51	2.9	4.7	1.5	-0.7	29.1	88.3
<i>PAHs</i>							
Acenaphthylene (µg/m ³)	0.083	<0.083	<0.083	0.00	0.00	0.00	0.25
Acenaphthene (µg/m ³)	0.083	<0.083	<0.083	0.00	0.00	0.00	0.10
Fluorene (µg/m ³)	0.083	<0.083	<0.083	0.00	0.00	0.00	0.15
Phenanthrene (µg/m ³)	0.083	<0.083	<0.083	0.00	0.00	0.09	0.15
<i>TSNAs</i>							
NNN (µg/m ³)	0.009	<0.009	<0.009	0.00	0.00	0.00	0.058
NAT (µg/m ³)	0.009	<0.009	<0.009	0.00	0.00	0.00	0.033
NAB (µg/m ³)	0.009	<0.009	<0.009	0.00	0.00	0.00	0.005
NNK (µg/m³)	0.009	<0.009	<0.009	0.00	0.00	0.00	0.599

Abbreviations:

EVP: Electronic vapour product
 LOQ: Limit of quantification
 NA: Not applicable
 NAB: *N*-nitrosoanabasine
 NAT: *N*'-nitrosoanatabine
 NNK: 4-(Methylnitrosamino)-1-(3-pyridyl)-1-butanone

NNN: *N*'-nitrosonornicotine
 PAH: Polycyclic aromatic hydrocarbon
 PM10: Particulate matter with a diameter of 10 µm or less
 PM2.5: Particulate matter with a diameter of 2.5 µm or less
 TSNA: Tobacco specific nitrosamine
 VOC: Volatile organic compound

by-product CO was greatest for conventional waterpipe use, and substantially lower for EVP and OOKA electronic waterpipe use, with the latter generating only a negligible amount of CO. The increase in formaldehyde levels was greatest for conventional waterpipe use and substantially lower for OOKA electronic waterpipe use. No increase in formaldehyde levels was observed during the one-occupant

EVP use scenario. A substantial increase in benzene levels was seen during conventional waterpipe use. A substantially lower increase in this analyte was observed during EVP use, but during OOKA electronic waterpipe use benzene levels were not increased above the one-occupant baseline.

For the ten-occupant scenarios, baseline levels of analytes

compared to the unoccupied baseline were observed for PM₁₀, PM_{2.5}, CO₂, and formaldehyde (Table 2 and [Supplementary Table 5](#)). In the ten-occupant product use scenarios (OOKA electronic waterpipe use, EVP use, presence of unattended conventional waterpipes, or cigarette smoking), levels of some of the analytes assessed were increased above the ten-occupant baseline for some or all scenarios. These included PM₁₀, PM_{2.5}, CO, CO₂, formaldehyde, benzene, toluene, ethylbenzene, and phenol (both predominantly during cigarette smoking), styrene (cigarette smoking only), naphthalene, NNN, and NNK (both cigarette smoking only; Table 2). When assessing these differences between scenarios, the increases in PM₁₀ and PM_{2.5} were greatest for EVP use and slightly lower for OOKA electronic waterpipe use, lower during the cigarette smoking scenario, and lowest for the unattended conventional waterpipes scenario. The increases in CO and formaldehyde were highest for the conventional waterpipes scenario, substantially lower during cigarette smoking, and negligible for OOKA electronic waterpipe and EVP use (Table 2). Of the metals, increases were seen for copper and manganese during the unattended waterpipe and cigarette smoking scenarios, respectively, but these were also negligible. The increase in benzene was highest during cigarette smoking, lower during the unattended conventional waterpipes scenario, and negligible during OOKA electronic waterpipe use. Increases in several other VOCs and some PAHs were mainly seen during cigarette smoking only and were negligible during the other product use scenarios. This pattern was similar for the TSNAs, NNN, NNK, and NAT (Table 2).

DISCUSSION

This study provides important insight into the potential for secondhand exposure to chemical toxicants during the use of several tobacco and nicotine products by measuring the levels of a large number of analytes in the air of an indoor testing facility during product use. Some of the toxicants assessed are found in the list of toxicants mandated by the World Health Organization for lowering in cigarette smoke (22). Of these toxicants, increases in the levels of CO (a cardiovascular and reproductive/developmental toxicant), formaldehyde (a carcinogen and respiratory toxicant), benzene (a carcinogen, cardiovascular toxicant, and reproductive/developmental toxicant), and NNK (a carcinogen) (23) observed in the one-occupant and unattended conventional waterpipes scenarios were either almost completely or completely abolished during the OOKA electronic waterpipe comparator scenarios. Additionally, the increases in the levels of these toxicants during OOKA electronic waterpipe use approximated to those observed during EVP use. These findings suggest that the electronic form of waterpipe use mitigates the potential risks due to secondhand exposure from conventional waterpipe use. Our findings of differential levels of analytes in room air in the waterpipe scenario compared with the cigarette smoking scenario are consistent with existing knowledge concerning the process of smouldering of the tobacco in shisha molasses and cigarette tobacco. Combustion in cigarettes is a self-sustained smouldering combustion char-

acterized by energetic exothermic (heat releasing) oxidative reactions that take place at 500 to 700 °C at the tip of the cigarette. These temperatures are raised to 850–900 °C when the smoker supplies extra oxygen by inhaling (24, 25). This energetic oxidation process can occur in tobacco biomass above its ignition temperature of approximately 400–450 °C, and its main chemical signature is the presence of nitrogen oxides and a steep increase in CO production which does not occur in an oxygen free atmosphere at same temperatures (25). When the cigarette is not actively smoked there is no external heat source, but the exothermic oxidation continues producing sidestream emissions, the chemical composition and phase partition of which is different from the mainstream emissions but includes carbon and nitrogen oxides. The smouldering process occurring during waterpipe use is physically and chemically different. Here, an external heat source ignites the charcoal briquette, which itself heats the contact surface of the tobacco in the waterpipe head by conduction through a layer of aluminium foil. The temperature also increases in spikes during puffing on the waterpipe, but compared with cigarettes, these increases are significantly smaller (26). This gives rise to characteristic temperatures of the waterpipe molasses which vary from 450 °C nearest the heat source to 50 °C furthest away, and the production of aerosol is likely a result of devolatilisation rather than a chemical reaction, and thus the aerosol differs significantly in composition compared to cigarette smoke (26). This explains the lack of PAHs and nitrogen dioxide found in indoor air during the waterpipe use scenarios in the present study, which is consistent with a previous study (21). In this regard, the amounts of CO in the room air relative to the number of waterpipes in the room were similar for the one-occupant using a waterpipe and the ten unattended waterpipe scenarios, which suggests that the release of CO into the air is inherent of the smouldering of the charcoal. Other analytes such as PM and formaldehyde were higher in room air during the waterpipe use session compared with the unattended waterpipes session when taking into account the number of waterpipes in the room, which suggests that these analytes are formed during puffing. The levels of these analytes would be expected to increase to levels higher than those observed in the present study if puffing were allowed on the conventional waterpipes instead of them being unattended in the ten waterpipe scenario. For this reason, it should be noted that our observations likely underestimate the potential reductions in analyte levels during OOKA electronic waterpipe use when compared with the unattended conventional waterpipes scenario. Additionally, leaving the waterpipes unattended during this scenario may remove the impact of changing the position of the charcoals during a use session. This typically happens periodically during a waterpipe use session and likely causes temporary alterations in waterpipe emissions. The findings of this study concerning the impact of conventional waterpipe use are broadly aligned with those in the literature. For example, DAHER *et al.* (9) reported a higher impact of conventional waterpipe use on levels of CO, benzo[*a*]pyrene, carbonyl compounds (e.g., formaldehyde, acetaldehyde, acrolein and propionaldehyde) in the indoor air of a testing chamber. In this study, a conventional waterpipe was used by a smoking machine which puffed on

the waterpipe according to a puffing regimen which had been predetermined based on user puffing topography (27). Findings qualitatively similar to ours, in terms of elevations of the levels of indoor toxicants associated with conventional waterpipe use, have also been described in studies assessing the impacts of actual, and not machine, use (19–21), although a number of these studies were conducted in uncontrolled environments such as waterpipe lounges, cafes and restaurants (19). Our findings therefore add to the body of scientific literature concerning levels of a number of potential chemical toxicants in indoor air and stem from a study which was rigorously controlled in terms of the use of a testing facility, and the numbers of participants during each testing session and their use of a discrete set of waterpipe test products.

We contribute to the existing literature by demonstrating that using an electronic waterpipe significantly mitigates the increase in analyte levels in indoor air compared to using a conventional waterpipe. In many cases, this mitigation was complete. The current study also adds to our recent analytical assessment of the levels of numerous analytes in the aerosol of conventional and electronic waterpipes (28). In their totality, the findings from both these studies represent a rigorous assessment of the potential for both direct and indirect exposure to chemical toxicants associated with conventional waterpipe use, and how both forms of exposure can be mitigated with an electronic waterpipe. Finally, our study provides additional information concerning the impact on indoor air quality of EVP use. Our findings suggest a limited impact of EVP use on the levels of the tested analytes in indoor air, both in absolute terms and also relative to scenarios involving the use of the combusted waterpipe and cigarette products. This concurs with other previous findings assessing levels of toxicants in indoor air during EVP use in various different real-world and laboratory environments (29–33), some of which have suggested that elevations in toxicants are of no apparent risk to human health (30).

Regarding our particulate matter findings, whilst all products in the study generated PM₁₀ and PM_{2.5}, the analytical equipment used does not distinguish between solid particles deriving from the products of combustion and liquid droplets. This is important since for the OOKA electronic waterpipe and EVP the particles detected are liquid droplets primarily composed of toxicologically inert glycerol, propylene glycol, and water which would have a different volatility and toxicological profile from those particles arising from cigarette smoking which are a mixture of both solids and liquid droplets and have a different chemical composition (34–41). Similarly, we and others have reported elevated levels of PM in indoor air during EVP use (33, 42–46). Due to the composition of EVP liquids, the majority of these particulates are likely to be toxicologically inert droplets of glycerol, propylene glycol, and water.

The findings from this study should be considered in the context of some limitations. Firstly, we assessed levels of a number of chemical analytes in the indoor of a testing facility. While the use of such a facility standardised our experimental approach, it may not necessarily represent real-world chemical levels in other environments which may have different volumes and dimensions, be subject to

different levels of ventilation, contain different types and numbers of furnishings, and be used by different numbers of waterpipe users. In this regard, our studies were conducted in a facility in the absence of either active or passive ventilation, and therefore our findings may overestimate the levels of chemical analytes in indoor air which are likely to be found in ventilated environments. Secondly, we assessed only a single type of waterpipe and charcoal, and a finite number of shisha molasses (one type in the one-occupant scenario and a small, finite number in the ten-occupant scenario). Our findings may not therefore be representative of other types of waterpipe/charcoal, or of other shisha molasses. The same principle applies to the cigarette smoking/EVP use scenarios, which also used a small and finite number of test products. Thirdly, we assessed the levels of airborne chemical analytes, and these are used as proxies for potential exposure. Additional studies would be required to determine whether passive exposure to conventional and electronic waterpipe aerosol leads to changes in biomarkers of exposure to chemical toxicants. Similarly, we are unable to use the data generated in this study in order to determine whether, and to what degree, passive exposure to waterpipe aerosol poses any risk to health.

In summary, in various use scenarios in which tobacco and nicotine products were used in an indoor testing facility we determined differential elevations in a number of potential chemical toxicants between the study products. Importantly, we were able to discern significant reductions or elimination of a number of toxicants in the indoor air during the use of an electronic waterpipe when compared with a conventional waterpipe. These findings have important implications concerning the potential for second-hand toxicant exposure among waterpipe non-users, and for understanding how to potentially reduce health risks associated with such exposure. They may also be used in a weight-of-evidence approach to enable an understanding of potential health risks in the population as a whole.

SUPPLEMENTARY INFORMATION

This publication contains supplementary material available at <https://reference-global.com/article/10.2478/cttr-2025-0021>

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of Al Futtaim Element Materials Technology Dubai LLC (Dubai, UAE) in conducting the study.

AUTHOR CONTRIBUTIONS

PJW, AC and RB designed the study. IMF assessed and contextualized the data and wrote the initial draft manuscript. All authors contributed to editing and approving the final manuscript.

FINANCIAL SUPPORT

This study was funded by Advanced Inhalation Rituals (AIR) Group Ventures.

CONFLICTS OF INTEREST

This study was funded by Advanced Inhalation Rituals (AIR) Group Ventures, a manufacturer of conventional shisha tobacco products including the Al Fakher Two Apples shisha tobacco assessed in this study, and of the OOKA electronic waterpipe and associated shisha tobacco pods. PJW, AC and RB are employees of Advanced Inhalation Rituals Ltd. IMF is a Non-Executive Director with Advanced Inhalation Rituals (AIR) Group Ventures, an independent consultant to tobacco and nicotine product manufacturers and contract research organisations, and a retained Scientific Advisory Board member of Qnovia, LLC. IMF holds shares in British American Tobacco and Qnovia, LLC.

REFERENCES

1. Almomen, S., M. Aldossari, Y. Khaleel, M. Altamimi, O. Alharbi, A. Alsuwaydani, M. Almutairi, S. Alyousef, R. Hafiz, F. Alshomer, and A.S. Alqahtani: Effect of Glycerol Concentration on Levels of Toxicants Emissions from Water-Pipe Tobacco Smoking (WTS); *BMC Public Health* 23 (2023) 1858. DOI: 10.1186/s12889-023-16740-2
2. Kienhuis, A.S. and R. Talhout: Options for Waterpipe Product Regulation: A Systematic Review on Product Characteristics that Affect Attractiveness, Addictiveness and Toxicity of Waterpipe Use; *Tob. Induc. Dis.* 18 (2020) 69. DOI: 10.18332/tid/125079
3. Tee, G.H., N.N. Hairi, F. Nordin, W.Y. Choo, Y.Y. Chan, G. Kaur, P.D. Veerasingam, and A. Bulgiba: Systematic Review on International Practices in Controlling Waterpipe Tobacco Smoking; *Asian Pac. J. Cancer Prev.* 16 (2015) 3659–3665. DOI: 10.7314/apjcp.2015.16.9.3659
4. Bhatnagar, A., W. Maziak, T. Eissenberg, K.D. Ward, G. Thurston, B.A. King, E.L. Sutfin, C.O. Cobb, M. Griffiths, L.B. Goldstein, and M. Rezk-Hanna: Water Pipe (Hookah) Smoking and Cardiovascular Disease Risk: A Scientific Statement from the American Heart Association; *Circulation* 139 (2019) e917–e936. DOI: 10.1161/CIR.0000000000000671
5. Jukema, J.B., D.E. Bagnasco, and R.A. Jukema: Waterpipe Smoking: Not Necessarily Less Hazardous than Cigarette Smoking: Possible Consequences for (Cardiovascular) Disease; *Neth. Heart J.* 22 (2014) 91–99. DOI: 10.1007/s12471-013-0501-0
6. Erythropel, H.C., D.S. Garcia Torres, J.G. Woodrow, T.M. de Winter, M.M. Falinski, P.T. Anastas, S.S. O'Malley, S. Krishnan-Sarin, and J.B. Zimmerman: Quantification of Flavorants and Nicotine in Waterpipe Tobacco and Mainstream Smoke and Comparison to E-Cigarette Aerosol; *Nicotine Tob. Res.* 23 (2021) 600–604. DOI: 10.1093/ntr/ntaa114
7. Yadav, S.: Decoding Waterpipe Tobacco Smoking: A Comprehensive Narrative Review Exploring Mechanics, Health Risks, Regulatory Challenges, and Public Health Imperatives; *Cureus* 16 (2024) e52168. DOI: 10.7759/cureus.52168
8. Yadav, S. and G. Rawal: Waterpipe Tobacco Smoking: A Mini-Review; *J. Transl. Intern. Med.* 6 (2018) 173–175. DOI: 10.1515/jtim-2016-0013
9. Daher, N., R. Saleh, E. Jaroudi, H. Sheheitli, T. Badr, E. Sepetdjian, M. Al Rashidi, N. Saliba, and A. Shihadeh: Comparison of Carcinogen, Carbon Monoxide, and Ultrafine Particle Emissions from Narghile Waterpipe and Cigarette Smoking: Sidestream Smoke Measurements and Assessment of Second-Hand Smoke Emission Factors; *Atmos. Environ.* (1994) 44 (2010) 8–14. DOI: 10.1016/j.atmosenv.2009.10.004
10. Chaouachi, K.: The Medical Consequences of Narghile (Hookah, Shisha) Use in the World; *Rev. Epidemiol. Sante Publique* 55 (2007) 165–170. DOI: 10.1016/j.respe.2006.12.008
11. Chaouachi, K.: A Critique of the WHO Tobreg's "Advisory Note" Report Entitled: "*Waterpipe Tobacco Smoking: Health Effects, Research Needs and Recommended Actions by Regulators*"; *J. Negat. Results Biomed.* 5 (2006) 17. DOI: 10.1186/1477-5751-5-17
12. Chaouachi, K.: Hookah (Shisha, Narghile) Smoking and Environmental Tobacco Smoke (ETS). A Critical Review of the Relevant Literature and the Public Health Consequences; *Int. J. Environ. Res. Public Health* 6 (2009) 798–843. DOI: 10.3390/ijerph6020798
13. Murphy, J., M. Gaca, F. Lowe, E. Minet, D. Breheny, K. Prasad, O. Camacho, I.M. Fearon, C. Liu, C. Wright, K. McAdam, and C. Proctor: Assessing Modified Risk Tobacco and Nicotine Products: Description of the Scientific Framework and Assessment of a Closed Modular Electronic Cigarette; *Regul. Toxicol. Pharmacol.* 90 (2017) 342–357. DOI: 10.1016/j.yrtph.2017.09.008
14. Berman, M.L., W.K. Bickel, A.C. Harris, M.G. LeSage, R.J. O'Connor, I. Stepanov, P.G. Shields, and D.K. Hatsukami: Consortium on Methods Evaluating Tobacco: Research Tools to Inform US Food and Drug Administration Regulation of Snus; *Nicotine Tob. Res.* 20 (2018) 1292–1300. DOI: 10.1093/ntr/ntx228
15. Hatsukami, D.K., L. Biener, S.J. Leischow, and M.R. Zeller: Tobacco and Nicotine Product Testing; *Nicotine Tob. Res.* 14 (2012) 7–17. DOI: 10.1093/ntr/ntx027
16. Institute of Medicine (IOM): Clearing the Smoke: Assessing the Science Base for Tobacco Harm Reduction; edited by K. Stratton, P. Shetty, R. Wallace, *et al.*, National Academy Press, Washington, DC, USA, 2001, 636 pp. ISBN: 978-0-309-07282-3. Available at: <https://nap.nationalacademies.org/catalog/10029/clearing-the-smoke-assessing-the-science-base-for-tobacco-harm> (accessed November 2025).
17. Stratton, K., P. Shetty, R. Wallace, and S. Bondurant: Clearing the Smoke: The Science Base for Tobacco Harm Reduction — Executive Summary; *Tob. Control* 10 (2001) 189–195. DOI: 10.1136/tc.10.2.189
18. Berman, M.L., G. Connolly, K.M. Cummings, M.V. Djordjevic, D.K. Hatsukami, J.E. Henningfield, M. Myers, R.J. O'Connor, M. Parascandola, V. Rees, J.M. Rice, and P.G. Shields: Providing a Science Base for the

- Evaluation of Tobacco Products; *Tob. Regul. Sci.* 1 (2015) 76–93. DOI: 10.18001/TRS.1.1.8
19. Kumar, S.R., S. Davies, M. Weitzman, and S. Sherman: A Review of Air Quality, Biological Indicators and Health Effects of Second-Hand Waterpipe Smoke Exposure; *Tob. Control* 24 Suppl 1 (2015) i54–i59. DOI: 10.1136/tobaccocontrol-2014-052038
20. Maziak, W., S. Rastam, I. Ibrahim, K.D. Ward, and T. Eissenberg: Waterpipe-Associated Particulate Matter Emissions; *Nicotine Tob. Res.* 10 (2008) 519–523. DOI: 10.1080/14622200801901989
21. Fromme, H., S. Dietrich, D. Heitmann, H. Dressel, J. Diemer, T. Schulz, R.A. Jörres, K. Berlin, and W. Völkel: Indoor Air Contamination during a Waterpipe (Narghile) Smoking Session; *Food Chem. Toxicol.* 47 (2009) 1636–1641. DOI: 10.1016/j.fct.2009.04.017
22. Burns, D.M., E. Dybing, N. Gray, S. Hecht, C. Anderson, T. Sanner, R. O'Connor, M. Djordjevic, C. Dresler, P. Hainaut, M. Jarvis, A. Opperhuizen, and K. Straif: Mandated Lowering of Toxicants in Cigarette Smoke: A Description of the World Health Organization Tobreg Proposal; *Tob. Control* 17 (2008) 132–141. DOI: 10.1136/tc.2007.024158
23. Food and Drug Administration (FDA): Website – Harmful and Potentially Harmful Constituents in Tobacco Products and Tobacco Smoke; Established List. Docket No. FDA-2012-N-0143. Available at: <https://www.federalregister.gov/documents/2012/04/03/2012-7727/harmful-and-potentially-harmful-constituents-in-tobacco-products-and-tobacco-smoke-established-list> (accessed November 2025).
24. Torero, J.L., J.I. Gerhard, M.F. Martins, M.A.B. Zanoni, T.L. Rashwan, and J.K. Brown: Processes Defining Smouldering Combustion: Integrated Review and Synthesis; *Prog. Energy Combust. Sci.* 81 (2020) 100869. DOI: 10.1016/j.pecs.2020.100869
25. Cozzani, V., F. Barontini, T. McGrath, B. Mahler, M. Nordlund, M. Smith, J.P. Schaller, and G. Zuber: An Experimental Investigation into the Operation of an Electrically Heated Tobacco System; *Thermochim. Acta* 684 (2020) 178475. DOI: 10.1016/j.tca.2019.178475
26. Shihadeh, A.: Investigation of Mainstream Smoke Aerosol of the Argileh Water Pipe; *Food Chem. Toxicol.* 41 (2003) 143–152. DOI: 10.1016/s0278-6915(02)00220-X
27. Shihadeh, A., S. Azar, C. Antonios, and A. Haddad: Towards a Topographical Model of Narghile Water-Pipe Café Smoking: A Pilot Study in a High Socioeconomic Status Neighborhood of Beirut, Lebanon; *Pharmacol. Biochem. Behav.* 79 (2004) 75–82. DOI: 10.1016/j.pbb.2004.06.005
28. Wilkinson, P.J., A. Clarke, I.M. Fearon, and R. Barry: Emissions from Conventional and Electronic Waterpipes Relative to Cigarettes and a Heated Tobacco Product; *Sci. Rep.* 15 (2025) 14176. DOI: 10.1038/s41598-025-90721-w
29. Czogala, J., M.L. Goniewicz, B. Fidelus, W. Zielinska-Danch, M.J. Travers, and A. Sobczak: Secondhand Exposure to Vapors from Electronic Cigarettes; *Nicotine Tob. Res.* 16 (2014) 655–662. DOI: 10.1093/ntr/ntt203
30. McAuley, T.R., P.K. Hopke, J. Zhao, and S. Babaian: Comparison of the Effects of E-Cigarette Vapor and Cigarette Smoke on Indoor Air Quality; *Inhal. Toxicol.* 24 (2012) 850–857. DOI: 10.3109/08958378.2012.724728
31. Oldham, M.J., A. Sehgal, G. Cohen, J. Chen, B. Evans, and D. Heraldez: Room Air Constituent Concentrations from Use of Electronic Nicotine Delivery Systems and Cigarettes Using Different Ventilation Conditions; *Sci. Rep.* 11 (2021) 1736. DOI: 10.1038/s41598-021-80963-9
32. Peruzzi, M., E. Cavarretta, G. Frati, R. Carnevale, F. Miraldi, G. Biondi-Zoccai, S. Sciarretta, F. Versaci, V. Cammalleri, P. Avino, C. Protano, and M. Vitali: Comparative Indoor Pollution from Glo, Iqos, and Juul, Using Traditional Combustion Cigarettes as Benchmark: Evidence from the Randomized Sur-Vapes Air Trial; *Int. J. Environ. Res. Public Health* 17 (2020) 6029. DOI: 10.3390/ijerph17176029
33. Schober, W., K. Szendrei, W. Matzen, H. Osiander-Fuchs, D. Heitmann, T. Schettgen, R.A. Jörres, and H. Fromme: Use of Electronic Cigarettes (E-Cigarettes) Impairs Indoor Air Quality and Increases FeNO Levels of E-Cigarette Consumers; *Int. J. Hyg. Environ. Health* 217 (2014) 628–637. DOI: 10.1016/j.ijheh.2013.11.003
34. Wright, T.P., C. Song, S. Sears, and M.D. Peters: Thermodynamic and Kinetic Behavior of Glycerol Aerosol; *Aerosol Sci. Technol.* 50 (2016) 1385–1396. DOI: 10.1080/02786826.2016.1245405
35. Zhao, T., C. Nguyen, C.-H. Lin, H.R. Middlekauff, K. Peters, R. Moheimani, Q. Guo, and Y. Zhu: Characteristics of Secondhand Electronic Cigarette Aerosols from Active Human Use; *Aerosol Sci. Technol.* 51 (2017) 1368–1376. DOI: 10.1080/02786826.2017.1355548
36. David, G., E.A. Parmentier, I. Taurino, and R. Signorell: Tracing the Composition of Single E-Cigarette Aerosol Droplets in Situ by Laser-Trapping and Raman Scattering; *Sci. Rep.* 10 (2020) 7929. DOI: 10.1038/s41598-020-64886-5
37. Martuzevicius, D., T. Prasauskas, A. Setyan, G. O'Connell, X. Cahours, R. Julien, and S. Colard: Characterization of the Spatial and Temporal Dispersion Differences between Exhaled E-Cigarette Mist and Cigarette Smoke; *Nicotine Tob. Res.* 21 (2019) 1371–1377. DOI: 10.1093/ntr/nty121
38. Zarvalis, D., P. Baltzopoulou, D. Deloglou, E. Daskalos, L. Chasapidis, E. Papaioannou, and G. Karagiannakis: Assessment of Particulate Matter Emissions from Tobacco Products; *Aerosol Air Qual. Res.* 25 (2025) 24. DOI: 10.1007/s44408-025-00011-3
39. Schlesinger, R.B., N. Kunzli, G.M. Hidy, T. Gotschi, and M. Jerrett: The Health Relevance of Ambient Particulate Matter Characteristics: Coherence of Toxicological and Epidemiological Inferences; *Inhal. Toxicol.* 18 (2006) 95–125. DOI: 10.1080/08958370500306016
40. Schlesinger, R.B.: The Health Impact of Common Inorganic Components of Fine Particulate Matter (PM_{2.5}) in Ambient Air: A Critical Review; *Inhal. Toxicol.* 19 (2007) 811–832. DOI: 10.1080/08958370701402382
41. Li, L., Y. Lin, T. Xia, and Y. Zhu: Effects of Electronic Cigarettes on Indoor Air Quality and Health; *Annu. Rev. Public Health* 41 (2020) 363–380. DOI: 10.1146/annurev-publhealth-040119-094043
42. Borgini, A., C. Veronese, C. De Marco, R. Boffi, A. Tittarelli, M. Bertoldi, E. Fernández, O. Tigova, S. Gallus, A. Lugo, G. Gorini, G. Carreras, L.P. MJ, X. Continente, S. Semple, R. Dobson, L. Clancy, S. Keogan,

- A. Tzortzi, C. Vardavas, *et al.*: Particulate Matter in Aerosols Produced by Two Last Generation Electronic Cigarettes: A Comparison in a Real-World Environment; *Pulmonology* 30 (2024) 137–144.
DOI: 10.1016/j.pulmoe.2021.03.005
43. Fernández, E., M. Ballbè, X. Sureda, M. Fu, E. Saltó, and J.M. Martínez-Sánchez: Particulate Matter from Electronic Cigarettes and Conventional Cigarettes: A Systematic Review and Observational Study; *Curr. Environ. Health Rep.* 2 (2015) 423–429.
DOI: 10.1007/s40572-015-0072-x
44. Li, L., C. Nguyen, Y. Lin, Y. Guo, N.A. Fadel, and Y. Zhu: Impacts of Electronic Cigarettes Usage on Air Quality of Vape Shops and Their Nearby Areas; *Sci. Total Environ.* 760 (2021) 143423.
DOI: 10.1016/j.scitotenv.2020.143423
45. Protano, C., P. Avino, M. Manigrasso, V. Vivaldi, F. Perna, F. Valeriani, and M. Vitali: Environmental Electronic Vape Exposure from Four Different Generations of Electronic Cigarettes: Airborne Particulate Matter Levels; *Int. J. Environ. Res. Public Health* 15 (2018) 2172. DOI: 10.3390/ijerph15102172
46. Protano, C., M. Manigrasso, V. Cammalleri, G. Biondi Zoccai, G. Frati, P. Avino, and M. Vitali: Impact of Electronic Alternatives to Tobacco Cigarettes on Indoor Air Particulate Matter Levels; *Int. J. Environ. Res. Public Health* 17 (2020) 2947.
DOI: 10.3390/ijerph17082947

Corresponding author:

*Peter Wilkinson
AIR Group Ventures
Festival Office Tower
Dubai Festival City
Dubai
UAE
E-mail: p. wilkinson@air.global*