An investigation of cooking-related pollutants in the residential sector

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ABSTRACT

In the residential sector, there are several indoor sources of pollutants related to activities such as cooking, cleaning and heating, besides those from occupants, building materials, finishing and furniture. Considering these sources, the kitchen appears as the space in the house that has the largest number of sources, with cooking being the most relevant source. In addition, meal preparation generates derivative processes related to cleaning utensils and the environment, in which detergents, air fresheners and other categories of cleaning products are used. The main goal of this study is to understand the main indoor pollutants in-kitchen, their source and transformation to further contribute to improve indoor air quality (IAQ). Therefore, an investigation focused on cooking-related pollutants is shown in the present study. The sources of pollutant related to the cooking process are separated in three main categories: the first is the type of fuel and stove, the second is related to the type of procedure used to prepare the food (frying, grilling, steaming, boiling and roasting processes) and the third is related to the type of food. The cleaning process including surface cleaners and dishwashing detergents is also discussed.

1 INTRODUCTION

Until a few years ago, the biggest concern was in relation to outdoor pollution, air, water and soil. However, it has now been recognized that indoor air pollutants (IAPs) play an equally important role in human health, comfort and productivity as a result of the increasing time we spend indoors (Paleologos et al., 2021; Shayegan et al., 2022). In many situations, indoor environments can be more polluted than outdoors (Alves et al., 2021; Guyot et al., 2022; Vicente et al., 2020; Zhang et al., 2021). The concern about exposure to IAPs has worsened due to COVID-19-derived restrictions. The pandemic has changed the work dynamics, such as the increase in remote work, cleaning frequency, cooking routine, more occupation, hence, more emissions and longer occupant's exposure (Guyot et al., 2022).

In residences, there are several sources of pollution in which the kitchen appears as the space in the house that has the largest number of sources, with cooking being the most relevant (Jeong et al., 2019; Pantelic et al., 2023). Many studies in the literature have reported that heating different oils can generate a wide variety of aldehydes and ketones (Zhang et al., 2023). Depending on the procedure used, the preparation of a complete meal can generate high concentrations of $PM_{2.5}$ (O'Leary et al., 2019), aldehydes (Alves et al., 2021) and PAHs (Saito et al., 2014). Furthermore, the type of stove/fuel also contributes to the IAPs formation (Lebel et al., 2022). Meal preparation generates derivative processes related to cleaning utensils and the environment, in which detergents and other categories of cleaning products are used.

Building materials and furniture are also important sources of VOC emissions, mainly in newly built houses (Harb et al., 2018; Poirier et al., 2021; Xu et al., 2022). The VOCs are one of the main causes of deterioration in IAQ and directly affect the health of humans harming the respiratory and nervous systems (Xu et al., 2022). Although building materials and furniture contribute significantly to the deterioration of IAQ, currently, due to the wide range of commercial products, emissions from these sources can be considered avoidable, unlike emissions from cooking processes. In this way, it is essential to develop technologies that reduce people's exposure to pollutants without changing the routine in dwellings.

This study brings an investigation of the main pollutants emitted in kitchens considering both cooking and cleaning activities. For the first one, the process involves the type of stove, the cooking procedure, and the type of food. The cleaning process considered the products related to cooking derivative activities such as cleaning utensils and the environment, hence, surface cleaners and dishwashing detergents were investigated. The information organized in this study may contribute to the development of modelling studies and implementation of policies to effectively improve indoor air quality in the residential sector.

2   POLLUTANTS RELATED TO COOKING PROCESS

In residential buildings, cooking is considered the primary source of pollutants and, in the kitchen environment, the pollutants are presented in both gas-phase and particulate-phase (Lai and Chen, 2007). The sources of pollutant related to the cooking process can be separated in three main categories: i) type of fuel and stove; ii) type of cooking procedure (frying, grilling, steaming, boiling, roasting processes, so on) and iii) type of food and its combination to compose a meal.

2.1   Type of cooking fuel

One of the first challenges is to identify the main fuels used worldwide, considering that there is a great diversity of customs within each country. Here, in this section, the most widespread ones in the literature are discussed.

Although new forms of energy have emerged to replace the use of firewood for cooking and heating, the solid fuels such as biomass and coal is still part of the energy matrix of many countries (Abdullahi et al., 2013; Gioda, 2019). According to the World Health Organization (WHO), around 3 billion people worldwide do not have access to clean cooking fuels and use open fires or simple stoves applying wood, charcoal, animal dung, crop residues, coal, and kerosene (Chomanika et al., 2022; Rupakheti et al., 2019). Kumar and collaborators (Kumar et al., 2022) performed a study in which they evaluated CO_2 exposure in kitchens of 12 major cities from 4 global regions. According to the authors, the cooking fuel type used in the homes evaluated are natural gas (NG), liquefied petroleum gas (LPG), kerosene, ethanol, electric and the different combinations of them (Kumar et al., 2022b). Likewise, in the emission inventory (EI) for the major anthropogenic sources of Indonesia performed by Permadi et al. (2017), it was shown that, in 2010, 46% of households used LPG for cooking, 39 % used fuel wood, 12% used kerosene and 3% used charcoal and coal (Permadi et al., 2017). Considering the aforementioned fuels, Table 1 presents the main emissions produced from each one.

Table 1: Main emissions related to the combustion of different fuels.

Fuel	Main emissions	Authors
Natural gas (NG)	CO_2, CO, steam, NO, NO_2, CH_2O, CH_4 and PM	(Lebel et al., 2022; Singer et al., 2017; Zheng et al., 2022)
Liquefied petroleum gas (LPG)	CO_2, CH_4, CO, SO_2, NO, NO_2, PM_{10}, $PM_{2.5}$ and HC	(Oke et al., 2020; Permadi et al., 2017)

Charcoal	CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, SO_2, CO, NOx, black carbon (BC), organic carbon (OC), non-methane volatile organic compounds (NMVOC)	(Permadi et al., 2017)
Ethanol	CO, CO_2, $PM_{2.5}$	(Chomanika et al., 2022)
Kerosene	CO_2, CH_4, N_2O, PM, SO_2, CO, NOx, BC, OC, NMVOC	(Permadi et al., 2017)
Coal	CO_2, CH_4, PM, SO_2, CO, NOx, BC, OC, NMVOC	(Permadi et al., 2017)
Raw wood-based fuel	CO_2, H_2O, NO, NO_2, SO_x, CO, CH_2O, PM and VOCs	(Kuye and Kumar, 2023)

Many countries have implemented policies to encourage the use of cleaner fuels for cooking and heating. After a government policy for switching kerosene fuel by LPG fuel in domestic cooking, the Indonesian kerosene usage decreased by 92% in less than ten years (Thoday et al., 2018). The government of Ecuador created a campaign called National Efficient Cooking Plan (NEFC) aiming to switching 3 million of LPG based cookers to electric induction stoves (Martínez-Gómez et al., 2016). A national energy strategy has also been developing in Nigeria to replace the kerosene and biomass fuel to a cleaner fuel such as ethanol (Ozier et al., 2018).

Chomanika et al. (2022) performed a study to compare the use of charcoal with ethanol briquettes by means of two different cookstoves named Chitetezo Mbaula (CM) and Kenya Ceramic Jiko (KCJ). The consumption of charcoal to prepare a complete meal in KCJ stove was high, reaching around 665 g of fuel per kg of cooked food (g/kg), while the consumption of ethanol briquettes was around 453 g/kg. The consumption of ethanol briquettes in the CM stove was 477 g/kg. The CO emissions from charcoal in the KCJ stove was 20.71 g/min while from ethanol briquettes in the KCJ and in the CM stoves the emissions rate were 0.029 g/min and 0.050 g/min, respectively. The $PM_{2.5}$ emissions rate were 1398.03 mg/min, 0.0931 mg/min 0.1009 mg/min from charcoal in KCJ cookstove, ethanol briquettes in KCJ and ethanol briquettes in CM stove (Chomanika et al., 2022).

Zhao and Zhao (2018) compared the use of gas stove with electric stove in pollutant emission. In a commercial kitchen, the concentration of CO, CO_2, NO, NO_2, and TVOC was reduced by around 40%, 26%, 86%, 42% and 48%, respectively, by replacing the gas stove by an electric stove. The authors also stated that steaming and stir-frying may result in higher concentrations of CO, CO_2, and TVOC in domestic kitchens. In the next section of the present study, the impact of cooking procedure is discussed, but here is important to note that the emissions of CO and CO_2 were not attributed only to cooking time and methods, but also occurred as a result of burning LPG (Zhao and Zhao, 2018).

Martínez-Gómes et al. (2016) performed a study comparing LPG, electric resistance and induction cookers in terms of CO and CO_2 emissions, time spent, energy consumption and final price during the preparation of typical Ecuadorian dishes. The induction stove was more efficient in all of evaluated parameters (Martínez-Gómez et al., 2016). The discussion regarding the CO and CO_2 emissions presents high correlations with the cooking procedure and type of ingredients, which is presented in more details in Sections 2.2 and 2.3 later. However, in a general view, the CO and CO_2 emissions presented the highest concentration when LPG stove was used due to the fuel combustion. As the total emissions are also time dependent (duration of each dish cooking process), the higher calorific power used in the LPG stove during cooking, the higher the CO_2 and CO emissions (Martínez-Gómez et al., 2016). For comparative purposes, during the preparation of grilled chicken considering hood idle mode, the CO_2 emissions reached 3500 ppm to LGP stove while the concentrations to induction and electric stove were near 500 ppm. The CO concentration reached 23 ppm to LGP stove and was lower than 4 ppm to induction and electric stove (Martínez-Gómez et al., 2016). In complement, compared to induction stove, the cooking time increased between 20% and 396% (depending on the dish) to LGP stove and between 200% and 1700% to electric stove. The energy consumption increased between 44% and 170% to LGP stove and between 24% and 80% to electrical stove. Finally, the energy consumption reflects the cost for final users – compared to induction stove, the final

cost increased between 41% and 167% to LGP stove depending on the dish and, between 24% and 80% to electric resistance stove (Martínez-Gómez et al., 2016).

2.2 Type of cooking procedure

Several studies have reported that the procedure used to prepare food has a great influence on the pollutant formation. Many methods are described in the literature such as boiling, grilling, steaming, stewing, braising, stir-frying, pan-frying, deep-frying and roasting (Zhao and Zhao, 2018). According to some authors, frying and grilling produces more particulate matter than boiling and steaming food processes, especially if the food is Maillard browned or charred. Balasubramanian 2008 (apud Zhao and Zhao 2018) investigated the $PM_{2.5}$ emissions related to different cooking methods of preparing tofu. The $PM_{2.5}$ average mass concentrations obtained during the cooking process of 150 g of tofu were: 65,7±7.6 µg/m^3, 81.4±9.3 µg/m^3, 120±13 µg/m^3, 130±15 µg/m^3 and 190±20 µg/m^3 for steaming, boiling, stir-frying, pan-frying and deep-frying processes, respectively. In some studies, the boiling process was shown to form more PM than the frying process, using the same food. However, the vapor emission can affect the performance of light scattering measurement devices. Furthermore, high relative humidity is related to hygroscopic growth of particles (aqueous aerosols), and larger particles can be more easily detected by analysers (O'Leary et al., 2019).

In addition to the preparation process itself, factors such as the type of pan also affect the indoor air pollutants. O'Leory et al. (2019) showed in their study that replacing a non-stick pan by a stainless-steel pan during meal preparation, resulted in a 940% increase in $PM_{2.5}$ emissions. Considering that the ingredients and the method of preparation used were the same in both experiments, the justification was in relation to the thermal conductivity of the pan, its surface temperatures, and the adhesion between the food and the pan. In the stainless-steel pan, it was observed that the food stuck to the surface, being charred later. However, the $PM_{2.5}$ formation decreased in subsequent experiments, indicating that the age of the pan may have an influence on emissions due to the changing properties of the pan's surface (O'Leary et al., 2019).

In the studies performed by Martínez-Gómez et al. (2016), it was presented that the cooking techniques, like boiling or frying, are responsible to increase the emissions of CO and CO_2. In addition, the authors showed how the frying process increased the concentrations of CO and CO_2. Although the preparation of grilled chicken was performed with the lowest final temperature, 72°C, this dish was the only one that used oil. However, the CO and CO_2 emissions resulted from this study are not only due to the cooking procedure, but also due to the LPG combustion. (Martínez-Gómez et al., 2016).

2.3 Type of food

The difficulty related to the pollutant analyses consist of all these parameters related to cooking fuel, procedure, ingredients, combination and catering types vary widely depending on the location and reflect economic and cultural factors, hence, the emission profiles cannot be generalised (Alves et al., 2021).

It is known that frying food is one of the procedures that emits the most pollutants (Liu et al., 2022). In this way, many studies have evaluated the difference among edible oils (Liu et al., 2022; Zhang et al., 2023), the effect of the addition of seasonings (Liu et al., 2017) and the combination of different ingredients to compose a complete meal (Zhang et al 2023; Alves et al., 2021; O'Leary et al., 2019). In studies carried out by Zhang et al. (2023), the formation of 13 aldehydes and ketones were identified during the use of 5 different edible oils – soybean oil, peanut oil, rapessed oil, sunflower seed oil and lard. The aldehydes and ketones identified were acetaldehyde, acrolein, propanal, methylacrolein, n-butyl aldehyde, amyl aldehyde, hexanal, acetone, methyl vinyl ketone, butanone, 2 - pentanone, 3 - pentanone and methyl isobutyl

ketone. The emission factor of aldehydes and ketones ranged from 250.87 µg/(goil.hr) to 436.12 µg/(goil.hr), being higher for rapeseed oil and lower for lard. For the 5 types of oil, the proportion of aldehydes in the total emissions varied between 61 and 78%, with acetaldehyde, acrolein and hexanal being the main compounds most formed. Liu et al. (2017) also evaluated the emissions resulting from the heating of corn oil. The main volatile organic compounds formed, dominated by aldehydes, were Ethanal, Propanal, Butanal, Methylpyrrole, Pentadienal, Toluene, 1,3-Cycloheptadiene/Phenol, Xylene/Benzaldehyde and Heptenal (Liu et al., 2017). Many authors also investigate the effect of adding seasonings on the formation of pollutants during the heating of edible oils and also during the preparation of complete meals (Liu et al., 2017; Zhang et al., 2023). The habit of stir-frying spices prior to stir-frying the food to improve the flavour of the dish is a common practice in some cultures (Liu et al., 2017). Despite the health benefits of using certain seasonings, this high-temperature stir-frying procedure can emit large concentrations of monoterpenes, which can later react with oxidants such as ozone and form a secondary organic aerosol (SOA) and thus affect health (Liu et al., 2017).

In studies carried out by Zhang et al 2023, chili powder, Chinese prickly ash and garlic slices were added to the oils. Emissions of aldehydes and ketones increased, with aldehyde being the largest proportion of total emissions, ranging between 59.3 and 71.5%. When chili powder, Chinese prickly ash and garlic slices were added to soybean oil, aldehyde emissions increased by 7.5%, 38.5% and 6.5%, respectively. When these spices were added to peanut oil, aldehyde emissions increased by 66.4%, 80.0%, and 14.9%, respectively. The authors correlated the addition of seasonings to the formation of larger molecular aldehydes; hence, their concentration was significantly greater compared to that of small molecular aldehydes (Zhang et al., 2023).

Liu et al., 2017 investigated the effects of adding garlic, ginger, myrcia and zanthoxylum piperitum (Sichuan pepper) in heated corn oil (stir-frying process). In addition to aldehydes, stir-frying spices also generated large amounts of other compounds. The stir-frying garlic process majority emitted the compounds methylpyrrole, dihydrohydroxymaltol and diallyldisulfide (DADS), the stir-frying ginger process emitted propanal, butanal, methylpyrrole, toluene, heptanal, monoterpenes and terpenoids, the stir-frying myrcia process emitted methylpyrrole, monoterpenes and terpenoids and, the stir-frying process of zanthoxylum piperitum emitted methylpyrrole, toluene, methylpyridine and monoterpenes. The addition of garlic and ginger to the heating corn oil almost had no influence on primary organic aerosol (POA) emissions. The POA concentration obtained due to the heating of pure corn oil, corn oil plus stir-frying garlic, ginger, myrcia and zanthoxylum piperitum in the reactor were approximately 42 µg/m^3, 44 µg/m^3, 46 µg/m^3, 71 µg/m^3 and 86 µg/m^3, respectively. Furthermore, garlic and ginger had no influence on SOA emissions, while large amounts of SOA were formed from the emissions of stir-frying myrcia and zanthoxylum piperitum (Liu et al., 2017).

The formation of pollutants during the preparation of complete meals is also widely studied and different emissions are reported. Zhang et al. (2023) compared the formation of aldehydes and ketones during the preparation of four different meals: Scrambled eggs with tomato and soybean oil, scrambled eggs with tomato and peanut oil, fried pork with chili and soybean oil and fried meat with chili and peanut oil. Acetone and acetaldehyde were the most abundant carbonyl compounds CCs in the kitchen. The highest acetaldehyde concentration (12329.93 ± 524.66 µg/m^3) was obtained during the fried meat preparation while the lowest was during the scrambled eggs with tomato and soybean oil (558.41 ± 27.47 µg/m^3). On the other hand, the last-mentioned meal presented the highest Acrolein concentration – 424.23 ± 17.46 µg/m^3 (Zhang et al 2023) being 100 times greater compared to the guidelines provided by Office of Environmental Health Hazard Assessment (OEHHA), ranging from 235.18 for scrambled eggs with peanut oil to 498.71 µg/m^3 for fried pork. O'Leary et al. (2019) compared the formation of PM$_{2.5}$ during the cooking of (1) chicken breast fillet and pre-sliced pre-cooked potatoes fried

in olive oil and French/green beans boiled in water, (2) chicken breast fillet fried in olive oil and French/green beans and pre-sliced pre-cooked potatoes boiled in water, (3) pasta Bolognese composed of dried farfalle durum wheat pasta boiled in water, smoked lean bacon lardons, chopped onion, tomatoes and garlic fried in olive oil and minced/ground beef fried in own fat and (4) stir-fry of pre-sliced chicken breast, pre-chopped fresh vegetables, white cabbage, red pepper/capsicum leek, French/green beans, bean sprouts and straight to wok noodles all of then stir-fried in olive oil. The highest $PM_{2.5}$ formation was obtained during the stir-fried chicken breast preparation (3.2 ± 0.24 mg/min), while the lowest concentration was obtained to meal 1 – chicken breast fillet (0.62 ± 0.041 mg/min). Saito et al. (2014) grilled different ingredients such as prawns, corn, trout, beef and pork to investigate the polycyclic aromatic hydrocarbons (PAHs) formation. The PAHs ranged from 0.0039 $\mu g/m^3$ for grilled corn to 78 $\mu g/m^3$ for grilled pork.

3   CLEANING PROCESS

The cleaning process involves products including floor/surface cleaners, dishwashing detergents and air fresheners (Huang et al., 2011). This study focused only on the cleaning products related to cooking process, i.e., surface cleaners and dishwashing detergents. These products are mainly sources of volatile organic compounds (VOCs), which can react with oxidants present in the environment as soon as they are emitted and generate secondary pollutants.

Huang et al. (2011) investigated the VOCs emissions from different cleaning categories including kitchen cleaners (KC) and dishwashing detergents (DD) in the household products in Hong Kong. The authors evaluated four different commercial products for each cleaning category. In addition, they evaluated the kinetic of reactions between the biogenic VOCs and the environmental oxidants hydroxyl radical (•OH) and ozone at 298 K. The results showed that within the same category, the chemical composition and concentration of individual biogenic VOC varied widely with household products considering their different functions and scents as indicated on the labels. The identified VOCs were α-Pinene, β-Pinene, Myrcene, p-Cymene, D-Limonene, Eucalyptol, γ-Terpinene, Linalool and α-Terpineol. No association was established between the presence of fragrance in the products and the VOCs emissions (Huang e al., 2011).

Milhem et al. (2021) investigated the emissions of 6 different essential oil-based cleaning products and the correlation between their fragrance chemicals and volatile fraction. The cleaning products were classified in 5 categories: 2 kitchen degreasers, 2 general (multiuse) cleaners, 1 surface cleaner, and 1 glass cleaner. Based on information given by the manufacturer, the natural fragrance of each individual product was lemon oil, eucalyptus oil, citrus oil, lemon oil, lavender oil and eucalyptus oil for kitchen cleaner 1 (KC1), kitchen cleaner 2 (KC2), multiuse cleaner 1 (MC1), multiuse cleaner 2 (MC2), surface cleaner (SC) and glass cleaner (GC), respectively (Milhem et al., 2021). The main terpenes identified in the 6 evaluated cleaning products were α-pinene, limonene, linalool, Eucalyptol, Cymene, Bergamol, Camphor, β-pinene, γ-terpinene, α-terpineol, Menthol, and others with the mass concentration varying from 1.0 ± 0.3 to 2230.8 ± 71.4 μg of terpene per g of product. The results showed no correlation between the total terpene mass concentrations in the liquid phase of the selected cleaning products with the total amount of terpenes transferred to the gas phase. The total gas-transferred concentrations varied from 125 ± 15 to 85225 ± 5500 $\mu g/m^3$. The multiuse cleaners (1 and 2) presented an equivalent volatile concentration in the gas phase of 27000 $\mu g/m^3$ whereas their total terpene mass concentrations in the liquid phase differed by a concentration ratio of 2:1. The surface cleaner SC1 and the kitchen cleaner KC2 presented similar pattern with the gas-transferred concentrations for both products reaching approximately 80 000 $\mu g/m^3$. However, the terpene content of the surface cleaner SC1 was half of that of the kitchen cleaner

KC2 (3200 ± 270 µg/g). In contrast, the two-household products SC1 and MC1 had equivalent terpene mass contents but gas-transferred concentrations that differed by a factor of 3 (Milhem et al., 2021).

To investigate the individual gas-transferred concentration using a microchamber experiment, the authors correlated the volatile/liquid fraction concentration ratio (V/L) with the saturation vapor pressure (VP) of the terpene pure molecules. This relationship was only met for a-pinene. For the other terpenes, the behaviour was not predictable, hence, the solvent properties showed higher influence in the transfer to the gas phase than the intrinsic properties of the pure molecule.

The experiments to evaluate the primary emissions after the application of essential oil-based product were performed under realistic application conditions, in a 1-m3 test chamber. This analysis was performed using one product from each category: SC1, MC1 and KC2. Considering the 23 TerVOCs contained in the three liquid cleaners, 19 of them were identified in the gas phase. For the three products, the results showed a fast increase after the cleaning application in which the total TerVOCs highest concentration peaks (300 ppb to SC1 and MC1 and 160 ppb to KC2) were achieved around 30 minutes. Then, a gradual decreasing was observed and, after 3.5 hours, the total TerVOCs concentration was approximately 100 ppm to SC1 and MC1 and 50 ppb to KC2. It is important to highlight that KC2 presented the highest concentration of TerVOCs (3200 ± 200 µg/g) in the liquid phase among the three cleaners, reinforcing the lack of correlation between the total terpene mass concentrations and the total amount of terpenes transferred to the gas phase (Milhem et al., 2021).

The authors also performed a temporal evolution of the mass emission rate profiles of individual TerVOCs of the three cleaning products (SC1, KC2 and MC1) to estimate the time required to each terpene to reach the maximum emission rate, the maximum reached value and the time in which the emission source is depleted. Then, the mass emission rate profiles were evaluated considering the air exchange-corrected concentration and also air exchange plus deposition-corrected concentration. For all terpenes evaluated, the time to reach the maximum emission rate was 8 min after cleaning and the magnitude of the peak emission rate was around 710 µg/h linalool from SC1, 1550 µg/h eucalyptol from MC1 and 5000 µg/h eucalyptol from KC2. Eucalyptol was the only terpene emitted from the three evaluated cleaning products, presenting a wide variation in the peak emission rate between them: 620 ± 20 µg/h for the SC1, 4900 ± 110 µg/h for the KC2 and 1460 ± 30 µg/h for the MC1. Limonene was emitted from two cleaning products: 240 ± 30 µg/h for KC2 and 1100 ± 80 µg/h for MC1. KC2 presented the highest emission rate between the cleaning products categories and the emission of eucalyptol and menthol from KC2 was exhausted within 50 min and after 30 min for limonene. The total TerVOC emissions from SC1 and MC1 were exhausted within only 24 min (Milhem et al., 2021). The emissions of formaldehyde, acetaldehyde and acetone (the oxygenated VOCs – OVOCs) were also investigated during the experiments with SC1, KC2 and MC1. The emission values varied from one product to another presenting ranges from 6 to 18 ppb to formaldehyde, 22 to 210 ppb to acetaldehyde and 18 to 108 ppb to acetone (Milhem et al., 2021). The maximum emitted concentration of formaldehyde was observed 3.5 h after the product has been applied, indicating delayed emission kinetics that may be related not only to a primary release of the cleaning product itself but also to other factors (Milhem et al., 2021).

4 CONCLUSIONS

This manuscript provides an investigation on the main sources of pollutants in kitchens. According to the findings, the related-pollutant emissions encompass a wide range of compounds such as CO_2, CH_4, particulate matter, SO_2, CO, NOx, volatile organic compounds (VOC), among others, varying in different concentrations depending on the type of stove, cooking fuel, cooking procedure, cooking ingredients and the cleaning products used. In many

evaluated studies, the contaminants exceeded the maximum threshold concentrations defined by the World Health Organization (WHO) based on health effects, indicating the importance of developing new strategies for reducing occupants' exposure.

5   ACKNOWLEDGEMENTS

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