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Panama City Dwellings: Ventilation and Residential Cooking Effects on Indoor Air Quality

Residencias en la Ciudad de Panamá: Ventilación y efectos en la calidad de aire interior debido a la cocción

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Abstract. Liquefied petroleum gas is a vital energy source for cooking globally. It's used for cooking in 45% of Latin American households, compared with 27% in Asia and 15% in Europe. In Panama, 90% of the population has access to liquefied petroleum gas, and 67.8% use it for cooking. This research examines the use of gas stoves in households in Panama City through a household survey and a case study based on the measurement of indoor pollutants to analyze the factors that influence pollutant emissions generated during gas cooking. A survey was conducted on ventilation practices, the use of control instruments, and knowledge of the impact of cooking on indoor air quality. Direct data on pollutant emissions were also collected. The objective was to learn about cooking and ventilation practices, as well as the awareness of indoor air quality in the sample and the concentration generated during food preparation. As a result, two main problems were identified: many kitchens lack windows, leading to higher concentrations of pollutants, and limited public understanding about the health effects of these pollutants, which reduces the use of preventive measures. Additionally, it was found that cooking methods such as frying and grilling generate the highest number of indoor pollutants, with temperature being the key driver of emission rates. These findings provide baseline data on indoor air quality trends in Panamanian homes, underscoring the importance of adequate ventilation and user awareness in alignment with air quality and ventilation guidelines.

Keywords. Cooking, gas stoves, indoor air quality, LPG, ventilation.

Resumen. El gas licuado de petróleo es una fuente energética esencial para la cocción a nivel mundial. Su uso varía según la región: en América Latina es utilizado por el 45% de los hogares, en Asia el 27% y en Europa el 15%. En Panamá, el 90% de la población tiene acceso al gas licuado de petróleo, destinándose el 67.8% al sector residencial en actividades de cocción. Con la finalidad de analizar los factores que influyen en las emisiones contaminantes generadas durante la cocción con gas, se recopilaron datos directos de los contaminantes emitidos en un hogar urbano de la Ciudad de Panamá y se aplicó una encuesta sobre prácticas de ventilación, uso de instrumentos de control y conocimiento de la población sobre el impacto de la cocción en la calidad del aire interior. Los resultados evidenciaron que los métodos culinarios como freír y asar producen mayores niveles de contaminación, siendo la temperatura el factor determinante en la intensidad de las emisiones. Asimismo, la encuesta identificó dos problemas principales: la ausencia de ventilación en las cocinas, debido a la ausencia de ventanas, y el desconocimiento generalizado sobre los efectos de estos contaminantes en la salud, lo que reduce el uso de medidas preventivas. Estos hallazgos proporcionan datos de referencia sobre las tendencias de la calidad del aire interior en los hogares panameños, lo que subraya la importancia de una ventilación adecuada y la concienciación de los usuarios en consonancia con las directrices sobre calidad del aire y ventilación.

Keywords. Cocción, estufas a gas, calidad de aire interior, GLP, ventilación.

1. Introduction

The importance of indoor air quality (IAQ) to general well-being has become increasingly evident, mainly because people spend a substantial fraction of their time indoors, where certain pollutants can be 2 to 5 times higher than normal outdoor concentrations [1]. In general, low- and middle-income countries have poor air quality, due to factors such as the development of large-scale urbanization and economic growth, which are mainly based on the burning of fossil fuels, in sectors such as industry and residential, leading to inefficient combustion [2], [3].

Emissions generated during these activities represent a challenge, as many of the world's population live in poor housing conditions that, together with poor ventilation, can affect comfort and health [4].

Within the Latin American region, Panama's recent greenhouse gas (GHG) emissions inventory [5] reports the contribution of different fossil fuels to CO2 equivalent emissions. As indicated, LPG is responsible for 61.8% of emissions in the residential sector, 33.1% in the commercial and institutional sector, and 5.1% in other sectors such as agriculture, forestry, and fishing, generating a total of 806.1 Kt CO_2 equivalent [5] giving information about the combustion-dependent processes in Panamanian households.

Different indoor air pollutants, including carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), and volatile organic compounds (VOC), usually concentrate in indoor environments [6]. Studies have suggested that concentration during cooking changes according to the type of food and the cooking method used [7].

Furthermore, the U.S. Environmental Protection Agency (EPA) notes that emissions from household devices for cooking, such as beef and poultry, are often significant for semi-volatile organic compounds and particulate matter [8]. Likewise, other studies have shown that the cooking procedure directly affects the formation of contaminants. Some authors mention that frying and grilling generate more particulate matter than boiling and steaming, emphasizing browned or charred foods [6], [9].

Some indoor pollutants may also originate outside. Still, most are usually emitted inside the building, such as when fuel is burned for cooking, so a lack of ventilation can worsen indoor air quality [10].

Employing practical range hoods can substantially reduce cooking-related emissions, with performance related to factors such as hood design and airflow rates [11]. Otherwise [12] pointed out that two-thirds of cooking activities are carried out without using these extraction systems, considering that, sometimes, despite having this instrument, the inhabitants do not usually use it. In this way, the influence of range hoods in reducing air pollutant exposure during cooking is limited.

Recognizing the importance of indoor air exposure, this study assesses indoor air quality in Panama City dwellings, where data on residential LPG use are scarce, by surveying occupants' cooking practices and ventilation habits, and later by experiments monitoring air pollutant concentrations in the kitchen.

The primary goal is to quantify the variation of contaminants according to the type of food and cooking method, as well as to characterize the cooking activities and ventilation conditions present in the sample households.

2. Materials and methods

The research corresponds to a descriptive study whose purpose was to obtain qualitative information from a random representative sample. Also, an experiment was conducted in the cooking area.

2.1 Survey design

This study considered the two most populous districts of the Republic of Panama, according the last XII Population and VIII Housing Census [13], to estimate the sample. The District of Panama with a population of 440,814 and San Miguelito 103,988, respectively. Using a finite-population formula for descriptive qualitative studies [14] with a 5 % margin of error yielded, we obtained that the minimum sample is 384 households. Before conducting a full survey, a pilot study involving 19 participants was conducted as recommended by Hernández et al. (2014) [15]. The final questionnaire, comprising 52 items on cooking methods, household characteristics, and ventilation, was reviewed and approved by the Institutional Committee for Bioethics in Research (CIBio-UTP) at the Universidad Tecnológica de Panamá and by the Ministry of Health's General Directorate of Public Health under the RESEGIS regulation.

To analyze survey population response and estimate the behavior of the indoor air pollutants concentrations, this study proposes to comprehensively assess the relationship between windows in the kitchen and the housing design, use of range hoods, insect screens in kitchen windows.

To analyze survey population response and estimate the behavior of the indoor air pollutants concentrations, this study proposes to comprehensively assess the relationship between windows in the kitchen and the household design, ownership of kitchen hoods, use of insect screens in kitchen windows, and knowledge about the influence of cooking on indoor air quality.

2.2 Experimental analysis

The experiment was conducted in a building apartment in the Panama district, using an LPG-fueled stove. The apartment has an open concept style (an interior design without walls between common, becoming a connected space) (figure 1 and table 1).

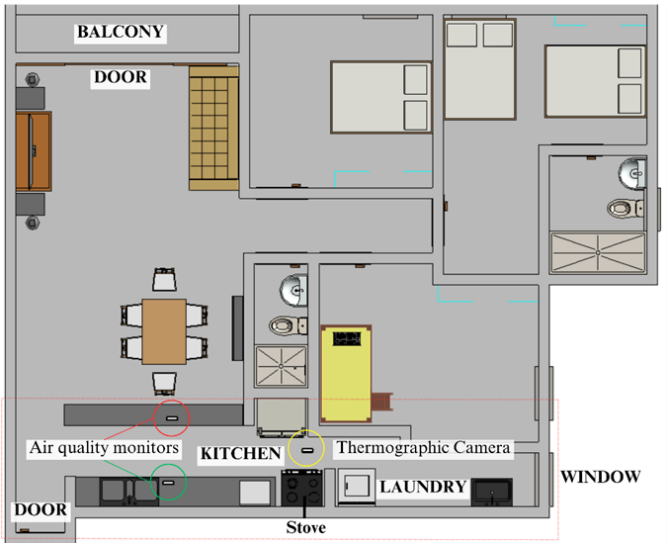

Figure 1. Kitchen experimental setup.

The red circle shows the location of the CO and CO_2 detector, the green circle indicates the PMx and VOC detector. The yellow circle indicates the thermographic camera.

Indoor air pollution was evaluated under minimum ventilation (doors and windows closed) and normal ventilation (doors and windows open). According to [16], Latin American cuisine focuses on three types of cooking methods: dry heat, moist heat, and combined cooking. In this case, the cooking methods selected were frying, boiling, and grilling. In this order of ideas, Panamanian gastronomy is characterized by high intake of rice, corn and chicken [17]; therefore, the food studied were rice, corn tortillas, and chicken. Five experimental scenarios were designed, combining two ventilation regimes with three cooking methods. Each experiment's cooking time was 5-10 minutes, and after each scenario, a 20-minute break was taken.

The $COCO^{2}{}_{-1}$ ratio, particulate matter, volatile organic compounds concentration during cooking, and the influence of food type and temperature on particulate concentration were estimated.

Table 1. Equipment and Sampling site

Variables /Air Pollutant	Instrument/ Equipment	Sampling site
Temperature	Fluke thermographic camera, model TIS55, 9HZ, resolution 246x192	It was located 30 cm away from the stove.
Carbon monoxide (CO), Carbon dioxide (CO_2)	HYVODNM air quality detector, model HTO-132	The sensors were located 2 m from the stove.
Particulate Matter 2.5 ($PM_{2.5}$) **Particulate Matter 10 (PM_{10})** **Total Volatile Organic Compounds (TVOC)**	Smart 126 s air quality monitor, BR-SMART BLATN	

3. Results and discusión

3.1. Survey

3.1.1 Cooking methods used by sample

According to the survey, the most reported cooking methods used were frying, boiling, and grilling, corresponding to 36%, 33%, and 31%, respectively (figure 2). The frying and grilling methods concentrate the most significant number of contaminants [18].

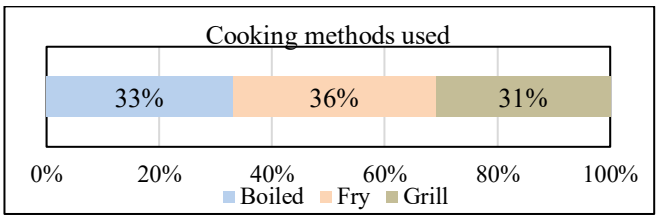

Figure 2. Cooking methods used according to the sample.

3.1.2 Ventilation conditions

3.1.2.1 Relationship between windows in the kitchen and dwelling design

In Latin America, the original design, characterized by building in stages from a base unit, is standard due to residents' need for expansion and the economic barriers to purchasing standardized urban housing that restrict future growth [19].

Therefore, this study analyzes the types of ventilation in kitchens according to the dwelling design. Defining original design as dwellings built with a unique plan or subsequently modified, while promoter design corresponds to single-family or apartment complexes dwellings, with a standardized design and shared with neighbouring houses. The results indicate that 80% of the dwellings analyzed have kitchen windows, of which 57% correspond to original designs and 43% to promoter designs. The remaining 20% are without windows, 51% are of promoter design and 49% of original design, as shown in figure 3.

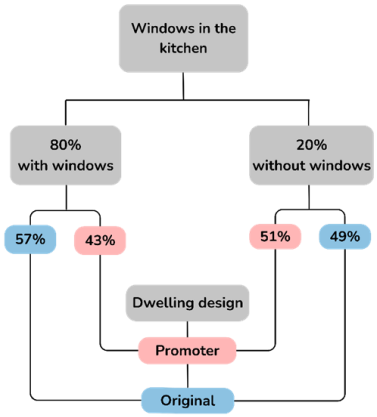

Figure 3. Relationship between kitchen windows and dwelling design.

Kitchen windows are associated with original designs, suggesting that homeowners tend to add windows to improve ventilation when modifying their dwellings, as opposed to standardized designs, where natural ventilation is often lower. This lack of windows affects a building's indoor air quality, causing inadequate ventilation, which contributes to a higher concentration of indoor pollutants [20], [21].

3.1.2.2 Type of windows used.

According to Panama's Liquefied Petroleum Gas Regulations, kitchen with LPG cylinders must have windows that allow permanent ventilation, such as decorative concrete blocks, and avoid those that may restrict it, such as French, jalousie, and hopper windows. In the sample, only 15% use decorative concrete blocks, which represents a violation of the regulation (figure 4).

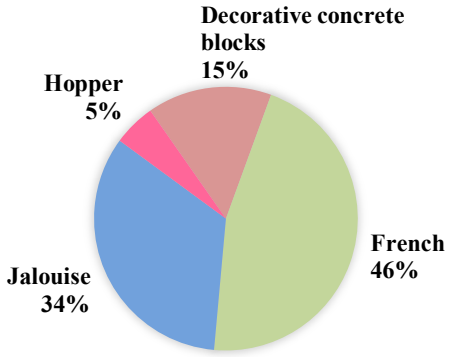

Figure 4. Types of windows used according to permanent ventilation (decorative concrete blocks) or non – permanent ventilation (hopper, French, jalousie).

According to the Air Conditioning and Ventilation Regulations for the Republic of Panama, the kitchen must have ornamental windows or windows that allow uninterrupted air inlets and outlets [22]. However, in the sample, only 15% use decorative concrete blocks, which represent a violation of the regulations, and an opportunity of improvement.

3.1.2.3 Use of range hoods in the kitchens.

In contrast, only 58% percent of the uses range hoods in the kitchen of their houses. In Panama, these hoods are not mandatory, and the one usually employ in the residential sector are ductless (Figure 5), recirculating the air instead of expelling it to the outside. Just 46.5% of dwellings with hoods expel the air to the outside, while 53.5% release it inside the kitchen, contributing to the accumulation of pollutants during cooking (figure 6).

Figure 5. Sample of ductless range hood used in Panama.

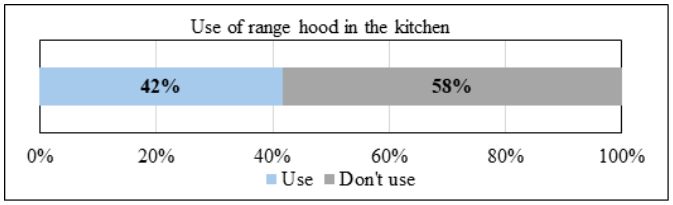

Figure 6. Use of range hood in the kitchen according to the sample.

3.1.2.4 Use of insect screens on kitchen windows.

In Panama, the Ministry of Health, as part of its Norms for Basic Measures for the Prevention and Control of Infections Associated with Health Care, recommends using window screens (Figure 7) to counteract the presence of insects inside the home [23], therefore, their use is shared among the population, as shown in Figure 8. Villagrán et al. (2020) [24], using computational dynamics simulations in greenhouses, reported that these screens can reduce air flow by more than 50% compared to spaces without them. Therefore, their presence significantly influences ventilation, even in areas such as the kitchen, where they can increase the concentration of contaminants. In the sample, 60% of the dwellings use these screens on kitchen windows, while 40% do not, suggesting a possible reduction in natural ventilation, as shown in figure 8.

Figure 7. Sample of insect screens used in Panama.

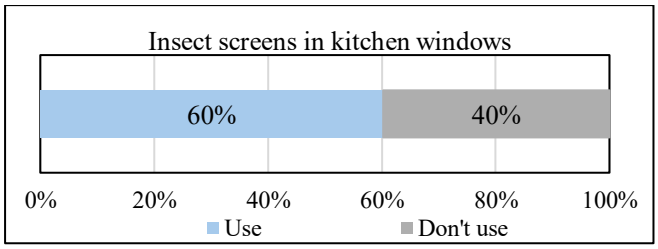

Figure 8. Use of insect screens in kitchen windows according to the sample.

3.1.2.5 Indoor Air Quality literacy in relationship with the use of monitoring tools.

The results showed that 67% of respondents were unaware of the influence of cooking on air quality in the home, while 33% were aware of it. Fire Code of San Francisco and the Housing Code (USA), require the installation of smoke and carbon monoxide detectors in homes, including their corresponding maintenance. These measures help prevent fires and control pollutants generated by cooking [25]. Based on this information, the survey asked about the use of these devices. However, using instruments to measure, detect, and improve air quality in both groups is low. This result reveals a contradiction: although some are aware of the problem, they do not use tools to mitigate it, possibly due to a lack of information or not considering the issue a priority (figure 9).

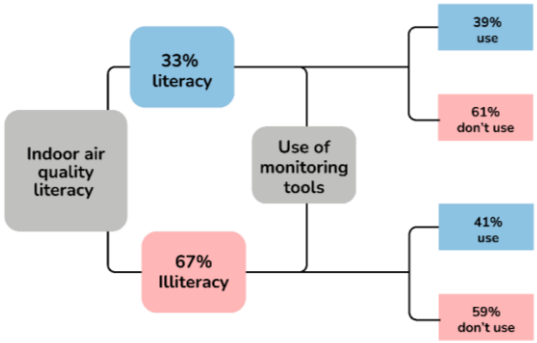

Figure 9. Relationship between indoor air quality literacy and use of monitoring tools in dwellings.

3.2 Experimental analysis

For the analysis of the experimental part, the COCO2-1 ratio was employed [7] to assess the gas stove combustion efficiency, with ideal values below 0.02 [26]. While cooking fried chicken under normal ventilation (blue line), values reached up to 0.07, indicating less efficient combustion compared to minimum ventilation (orange line), which consistently showed values near 0.02 (Figure 10). This inefficiency may stem from presence of oxygen affecting the air-gas mix, reducing flame intensity and temperature, leading to incomplete combustion and higher CO formation. According Mortari et al. [7] study, cooking methods like boiling or frying also elevate CO and CO2 emissions.

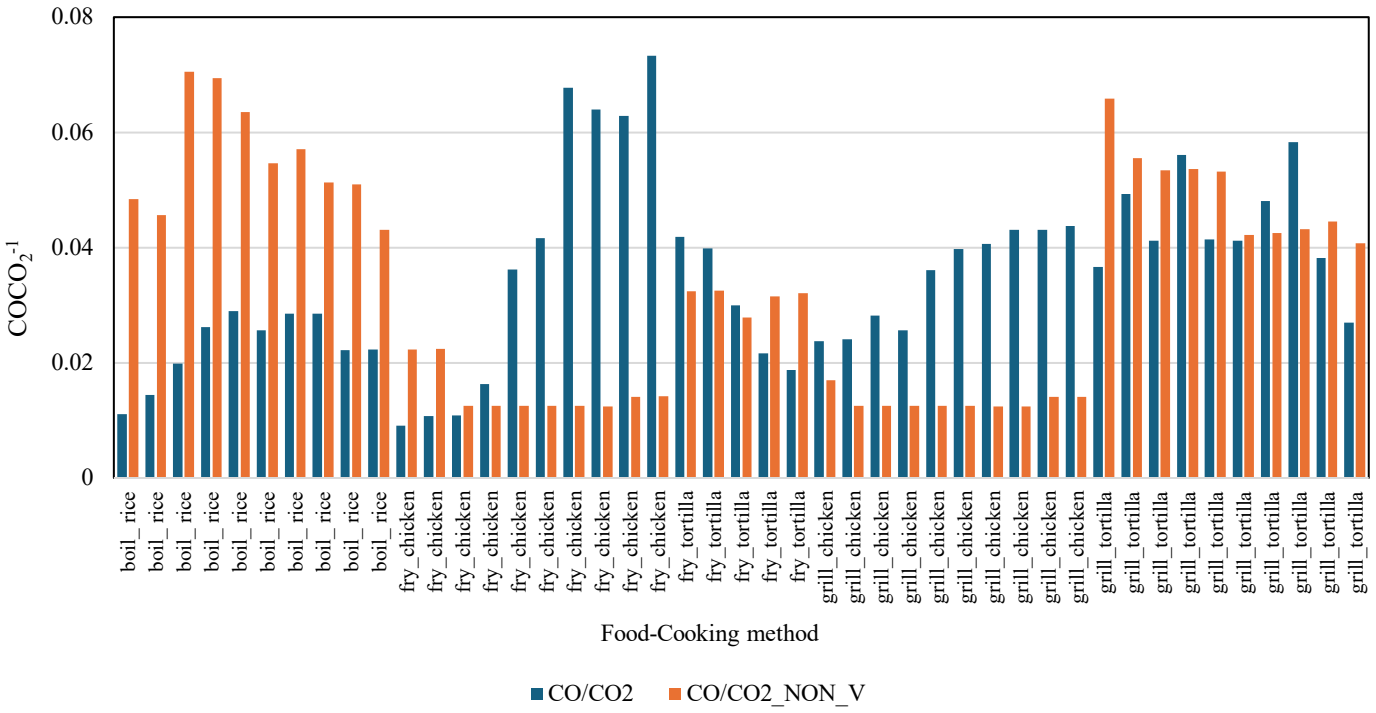

Figure 10. COCO2-1 ratio by cooking method.

Similarly, other studies [27], [28] reports that CO concentrations under 1,000 ppm reflect good ventilation and air exchange conditions, which this study also demonstrated.

In contrast, grilling under normal ventilation generates more particles than frying, especially when cooking chicken, likely due to higher temperatures and incomplete combustion. Frying emits fewer particles due to heat distribution. Chicken releases more particles than tortillas, as it contains more fat and protein in the same conditions than before. However, under minimum ventilation, chicken grilling produces high PM10 levels (up to 130 µgm-3). In contrast, tortillas emit much less (<25 µgm-3). Frying chicken also produces high PM10 (around 350 µgm-3), whereas tortillas remain below 150 µgm-3. In the case of rice, all the values were under 25 µgm-3 (figure 11).

Furthermore, higher oil temperatures increase VOC concentration, with deep frying generally producing the most $PM_{2.5}$, although stir-frying can emit 3–5 times more VOCs than deep frying in many cooking oils [29], [30]. In this study, TVOC concentrations exceeded particulate levels across all cooking methods, peaking during fried tortillas and grilled chicken, as reflected in figure 12.

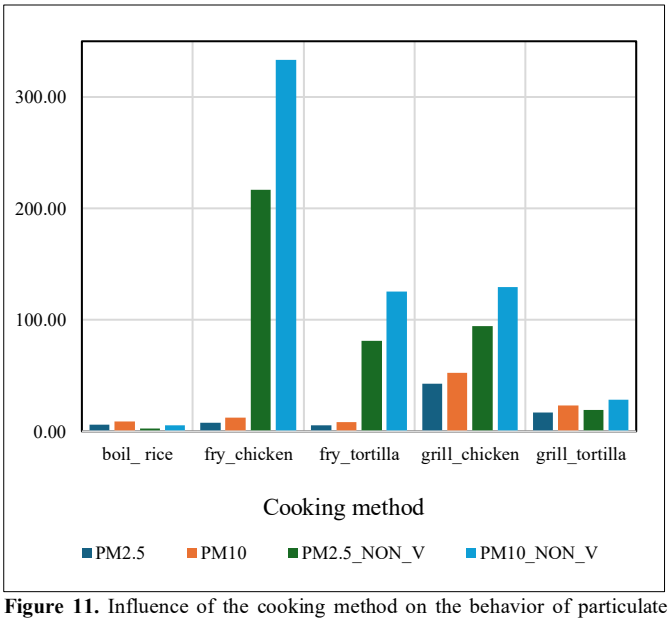

Figure 11. Influence of the cooking method on the behavior of particulate matter under normal ventilation conditions, minimum ventilation conditions (NON_V).

Under minimal ventilation, frying and grilling chicken drove TVOC concentrations above 2,000 μgm^{-3}, illustrating how high-temperature cooking release large volumes of gaseous pollutants. Since indoor VOC levels (50–300 mgm^{-3}) can far exceed outdoor concentrations and roughly 25 % are known or suspected carcinogens, adequate ventilation is critical to reduce resident exposure [31].

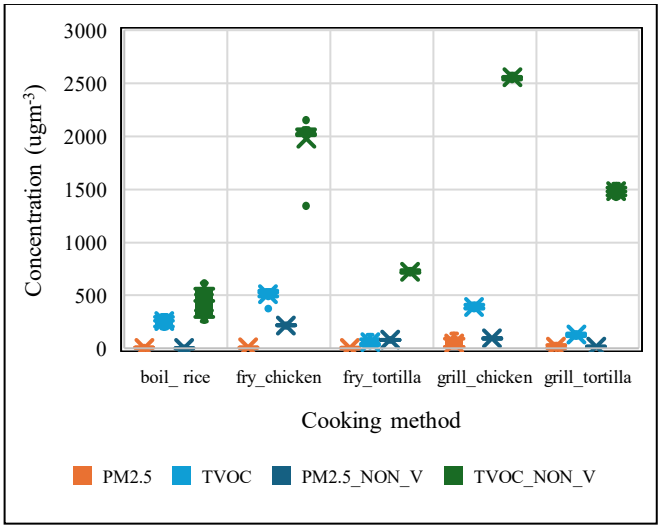

Figure 12. Relationships between indoor residential activities and total volatile organic compound (TVOC) concentrations under normal ventilation and minimum ventilation (NON_V).

Similarly, Buonanno et al. (2009) reported that adequate ventilation reduces up to 60% of the $PM_{2.5}$ emitted during cooking activity [32] and this pattern stands out during the development of this experiment, where fewer particles were generated in the presence of ventilation.

4. Conclusiones

The results of this study show that ventilation conditions, cooking methods, and household habits significantly influence indoor air quality. Although many dwellings have natural ventilation in Panama, the absence of kitchen range hoods and frequent cooking methods such as frying and grilling, especially with fatty foods like chicken, leads to high concentrations of nonvolatile particles and volatile organic compounds (VOCs). Moreover, the general lack of awareness among the population about indoor air pollution highlights the need for education and effective control measures, such as proper extraction systems, to protect residents' respiratory health.

Finally, this research highlights the following findings:

Compared with normal ventilation, minimal ventilation conditions increase particulate concentrations and home temperature, highlighting the importance of effective extraction systems to minimize indoor particle exposure.

Although most Panamanian homes have natural ventilation in kitchens, such as windows, the minority of those homes that do not have such ventilation are linked to the promoters' designs prepared, which is especially striking given that the construction of residential buildings is on the rise.

The Panamanians do not usually install extractors in the kitchen area to improve air quality when cooking food, even though, the methods they used the most were those that generated the highest emissions.

Most Panamanians know little about pollution in the home when cooking. Therefore, they do not usually consider the importance of using tools to monitor or improve the indoor air quality.

In relation to the experimental section, compared with tortillas, chicken generates more nonvolatile particles because of their higher fat and protein content, which release solid particles when cooked. As a matter fact, tortillas, which are low in fat and relatively simple in composition, emit significantly lower concentrations.

Studies indicate that LPG components are harmful to human health, such as CO, and can react with other organic compounds and thus generate other reactive chemical substances; in the same way, cooking processes are generators of aromatic compounds such as benzene and toluene (15). This is why special attention should be given to VOCs and $PM_{2.5}$ emissions, as they can penetrate deeply into the respiratory system, posing significant health risks.

Compared with frying, grilling generates more nonvolatile particles, especially for chickens. This may be due to the higher temperatures and direct contact of the food with the heat source during grilling, which increases the formation of solid particles and aerosols.

Cooking methods not only influence people's food health but also affect the indoor air quality of homes, considering that, in Panama, fried foods and grill-type cooking are frequent due to culinary customs.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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