IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 16, Issue 12 Ser. II (December 2022), PP 15-24
www.iosrjournals.org

Indoor air quality by fuel and kitchen type: KAP survey and pollutant measurement campaign

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ACKNOWLEDGMENTS
We thank the population of ToubabDialaw for their collaboration.

Abstract
Each year, 3.8 million people die prematurely from diseases attributable to indoor air pollution resulting from the inefficient use of solid fuels and oil for cooking. In Senegal, in rural areas, people depend on natural resources for their daily energy needs, such as wood, agricultural residues, dry manure, and charcoal. The aim of this study was: i) to determine the level of knowledge, attitude and practice about air pollution of the population in Toubab Dialaw; and ii) to evaluate the level of indoor air quality according to the types of kitchens and the fuels used for cooking. Three types of kitchens were found: open kitchens in the courtyard (58.46%), closed kitchens with windows (36.9%), and closed kitchens without windows (4.62%). Majority of households used butane gas as their main energy source for cooking (95.4%). This source is complemented by the use of charcoal more than 3 times a week. Levels of PM_{10}, CO and CO_2 are significantly influenced by the type of cooking fuel (Kruskal Wallis test, p< 5%). Pairwise comparison using Dunn's post hoc test shows that households using wood or charcoal had higher PM_{10} and CO concentrations gas compared to those using butane. About the types of kitchens, no statistically significant difference was observed (Kruskal Wallis test, p-value>5%). In view of the results, information and awareness-raising campaigns on indoor air pollution and its adverse effects need to be strengthened. Indoor air quality would be more associated by fuel types. It is essential to assess the respiratory health of residents exposed to biomass burning.

Keyword
Cooking fuel, indoor air, type of kitchen, Toubab Dialaw

Date of Submission : 07-12-2022 Date of Acceptance: 21-12-2022

I. Introduction

According to WHO, nearly three billion of poor people in the world still use solid fuels (wood, animal dung, mineral charcoal, plant debris and charcoal), which they burn in highly polluting and energy inefficient stoves. These fuels and cooking methods produce a multitude of indoor air pollutants that can cause adverse health effects (WHO, 2022). Each year, 3.8 million people die prematurely from diseases attributable to indoor air pollution resulting from the inefficient use of solid fuels and oil for cooking (WHO, 2022). This indoor air pollution is responsible for pneumonia (27%), ischaemic heart disease (27%), chronic obstructive pulmonary disease (20%), stroke (18%) and lung cancer (8%) (WHO, 2022).

In developing countries, biomass combustion is a common source of household energy and may cause indoor air pollution. Biofuels are burned in open fires or sometimes defective clay or metal stoves. In these stoves, combustion is very incomplete, leading to high emissions, which, in the absence of good ventilation, cause heavy indoor pollution (Sana et al., 2019). In Senegal, in rural areas, people depend mainly on natural resources for their daily energy needs, such as wood, agricultural residues, dry manure, and charcoal. Biomass represents more than 80% of the domestic fuel consumption balance in Senegal (Peracod, 2011). A survey conducted in Niakhar, a rural community, showed that 92% of households used traditional open fire, and less than 1% of households owned a liquid propane stove as their main cooking appliance (Hooper et al., 2018).

In addition, the cooking time of Senegalese dishes (4 hours on average) is a factor contributing to the degradation of indoor air quality. The frequent use of incense, especially during the tropical winter period, to heat and perfume bedrooms and living rooms, is also a source of pollution in most homes in Dakar. The incense burners used for burning are still largely traditional, even if in wealthy areas electric incense burners are gradually becoming the norm. All these practices are the cause of respiratory diseases, especially in sensitive people such as asthmatics and infants.

The preservation of indoor air quality has therefore become a health and environmental issue today. However, little data is available to raise awareness and convince Senegalese authorities of the urgent actions needed to curb this phenomenon.

The objective of this study is to determine the level of knowledge, attitude and practice of the population about air pollution; and to evaluate the level of indoor air quality according to the types of kitchens and the fuels used for cooking.

II. Materials and methods

Setting and study design

This is a cross-sectional study combining a KAP (Knowledges, Attitudes and Practices) survey and air quality metrology. The study took place from 25June to 26 July 2018, in Toubab Dialaw (14°36'22" N and 17°9'1" W), a semi-rural district located about 40 Km west from Dakar. Toubab Dialaw is a fishing village that stretches along a rather wild and little frequented beach. It is credited with 3000 inhabitants with 206 households on 157 concessions, mainly composed of Lebous (Ndong Ba et al., 2019).

Two dominant types of housing were identified: low-standard houses (traditional houses with a large number of rooms for living purposes, generally opening onto a large courtyard) and modern-type individual houses (more modern constructions with varying standards). Kitchens were either open to the courtyard (open fire) or closed in a room with or without windows.

Data sampling and collect

KAP survey: This cross-sectional survey aimed mainly to describe the characteristics of the dwellings (number of rooms, living space, etc.), the occupation of the space (mode of occupation, household composition, etc.), the types of fuel used (cooking with firewood, charcoal or butane gas), the duration of cooking, the other activities that emit pollutants (burning incense, smoking, etc.), and the perceptions and beliefs regarding air pollution and its impact on respiratory health.

Following a reasoned choice of sample size depending on the financial resources allocated, 65 households were surveyed out of the 206 existing households in the village.

The choice of households to be surveyed by zone was made using the itinerary method. To ensure that the study area was representative, the village was divided into four zones: North, South, East, and West. After the random selection of a reference household in each zone to start the interview, the closest household to the previous one was then selected until 16 households per zone were reached. In the case of the selected concessions, only one household was randomly approached. In case of refusal, another household in the same concession was chosen and replaced by the previous one.

In each selected household, the head or the woman of the household or one of the residents aged at least 18 years were interviewed. Particular emphasis was placed on respecting anonymity, confidentiality and obtaining the participant's informed consent, in accordance with the approval of the Research Ethics Committee of Cheikh Anta Diop University (UCAD-Dakar-Senegal) (Protocol 0091 / 2015 / CER / UCAD).

The persons solicited were informed of the voluntary and unpaid nature of their participation, of the objectives and methods of the study and of the expected benefits. Their informed consent was formally sought in writing before participation.

Indoor air quality metrology: Following the results of the survey, households were measured for air quality according to the different types of cooking fuels used (butane gas, charcoal and firewood), taking into account the types of kitchens (closed kitchens without windows, closed kitchens with windows and open kitchens). Three measurements were made in each selected household. Two different devices were adopted for the campaign of air quality measurement: the EVM-7 environmental monitor and the AQ Pro indoor air quality monitor.

EVM-7 (version 1.05 Quest Technologies) is a compact environmental monitor for the measurement of the airborne concentrations of PM and gases (CO_2 and CO), it also measures meteorological parameters such as humidity and temperature in thirty second (30 sec) intervals. The particle sampling involves a 90° laser photometer that measures and stores suspended dust concentration levels over time. The methodology used involves a handful of components including an air inlet, impactor (which is the particle size selector), particle collection, gravimetric sampling (filtering into the gravimetric cassette) and pump with a flow rate of 1.67 Litres per minute. Air flows through the impactor and the larger, heavier particles adhere to the greased plates of the impactor. While the pump maintains the flow, the smaller, lighter particles (selected PM) pass through the optical engine. The particles will then accumulate in the filters of the gravimetric cassettes. The remaining filtered air passes through the pump and then the flow sensor. Finally, it passes to the outlet on the back of the instrument. For gas sampling, the EVM uses sensors to measure up to three gases simultaneously. The results are processed by the 3MTM Detection Management DMS software.

A simultaneous, multi-sensor gas detector, AQ Pro indoor air quality monitor, was configured to detect the concentration of NO and NO_2through their three electrode sensors. Normal air movement is enough to carry air samples to the monitor which collects the sample by diffusion. It is equipped with an internal filter to eliminate interference with other acid gases. The data is recorded in thirty second (30 sec) intervals. The evaluation of the results is processed by the AQ GASTM software.

These devices have been previously calibrated and have demonstrated good stability. They were placed about 1.5 m above the ground, at the entrance to the kitchen. The measurements were carried out for 4 h after the start of lunch cooking (corresponding to the average cooking time in Senegal).

Statistical analysis

All statistical analyses were performed using statistical analysis software R for Windows. In the first hand, frequency measurements for the qualitative variables and parameters summarizing the distribution of the quantitative variables collected during the cap survey were performed and in the second hand a bivariate analysis using the Kruskal Wallis test is also performed to determine the influence of the type of cooking fuel as well as the type of kitchen on the air quality levels. If the Kruskal Wallis test is significant, a pairwise comparison test is performed using Dunn's post hoc test. A p-value of less than 0.05 was considered statistically significant.

III. Results and discussion

KAP survey

Characteristics of households and survey respondents: In total, 65 respondents with 1 per household, aged 40 years on average and mostly female (56% women and 43.1% men) participated in the KAP survey. The households were generally traditional houses (98.5%), which are low-standard concessions with a common courtyard. Almost all households had more than three habitable rooms with an average of 12 residents per household. This reflects the social character of the inhabitants who remain attached to their traditional homes.

Three types of kitchens were found: open kitchens in the courtyard (58.46%), closed kitchens with windows (36.9%), and closed kitchens without windows (4.62%). The proportion of open kitchens in our study site is higher than in the city of Dakar (7.7%) and the commune of Ouagadougou (38.82%) (Kafando, Savadogo, Millogo, et al., 2019). Indeed, open cooking is a more common practice in rural areas to reduce the level of exposure to pollutants from biofuel smoke. Increasing air change rates would reduce $PM_{2.5}$ concentrations by 93-98% and CO concentrations by 83-95% compared to closed kitchens (Grabow et al., 2013) .

Majority of households use butane gas as their main energy source for cooking (95.4%). This source is complemented by the use of charcoal more than 3 times a week by 63.1% of respondents. However, surveys conducted in Niakhar, a rural area located in the Fatick region (Senegal), revealed in 2009 that 100% of households (15/15) used wood (twigs and branches) as their main fuel source (Pavlinac et al., 2010). The revised survey in 2012 shows that less than 1% of LPG-owning households used this stove exclusively, or even as the primary device (Hooper et al., 2018). This difference with our study site could be explained by the availability and accessibility of biofuels throughout the year in Niakhar (wood during the dry months and crop residues during the rainy season) (Hooper et al., 2018). It could also be linked to the income level of the inhabitants in Toubab Dialaw (81.5% of households have net incomes between 55,000 and 100,000 per month). Indeed, the choice of cooking fuel depends on socioeconomic status, the woman's level of education, and the size of the family (Hooper et al., 2018; Sana, 2020). In addition, 80% of these households burn incense several times a week as shown in table 1 below.

Table 1: Characteristics of households and survey respondents

Characteristics of respondents		**Median**	**Average**	**Standard deviation**
Age		40	42.462	13.163
Number of years in the household		12	15.034	11.752
			N = 65	
			n	**%**
Sex	Male		28	43.1
	Woman		37	56.9
Marital status	Single		6	9.2
	Married		56	86.2
	Widow(er)		4	4.6
Employment status	Employee (public/private)		20	30.8
	Trader		16	24,6
	Housekeeper		19	29.2
	Other		10	15.4
Net monthly household income, including non-wage income	Less than CFAF 50,000 per month		9	13.8
	From 50, 000 to 100, 000 CFAF per month		53	81.5
	From 100, 000 to 300, 000 CFAF per month		2	3.1
	don' t know/Refused		1	1.5
Characteristic of households				
Type of household	Low standard house, shared courtyard		64	98.5
	Housing in a block of flats		1	1.5
Types of kitchens	Closed, with window		24	36,92
	Closed without window		3	4,62
	Not closed (in the yard)		38	58,46
Number of habitable rooms in the dwelling	Two pieces		1	1,54
	Three pieces		12	18,46
	Four pieces		12	18,46
	Five pieces		11	16,92
	More than five pieces		29	44,62
The Main source of energy for cooking	Wood		1	1.5
	Coal		2	3.1
	Butane gas		62	95.4
Other sources used more than 3 times a week	Wood		22	33.8
	Coal		41	63.1
	Butane gas		2	3.1
Use of plastic bags for burning wood	Yes		5	7.7
	No		58	89.2
	Don't know		2	3
Incense burning	Yes		52	80.0
	No		12	18.5
	Don't know		1	1.5
		Median	**Average**	**Standard deviation**
Number of residents in the household		12	13.769	6.91

Number of children under 5 years old	1	1.785	1.816

General knowledge about air quality: General knowledge about air quality includes perception of air quality, indoor air degradation factors, and Health risks from air pollution, as shown in table 2. The population has a fairly good perception of air quality and its degrading factors, as well as of the health risks arising from air pollution. Indeed, the majority thinks that tobacco smoke, kitchen smoke, incense, burning of household waste (respectively cited by 96.92%, 92.31%, 93.85% and 98.46% of respondents) contribute to air pollution in the dwellings. However, they have limited knowledge about the contribution of dust mites (lice, bedbugs) and molds to indoor air pollution. However, skin sensitization to dust mites is common in Africa, particularly in Morocco and Senegal. This is the conclusion of a study conducted in the Maghreb and sub-Saharan Africa in a population of patients consulting for rhinitis and/or asthma (El Fekih et al., 2014). A description of the clinical allergic symptomatology such as nasal pruritus, runny nose, sneezing, coughing, etc., would help to improve respondents' understanding of the contribution of dust mites and molds to the degradation of indoor air quality.
The population of Toubab Dialaw mainly associates the environment with the quality of water (38.46%), followed by air in cities (20%), then the climate (16.92%). This perception is explained by the fact that villagers are confronted with the problem of running water in some areas. Generally, they resort to well water, which is often contaminated by a rainwater runoff, leading to wastewater from septic tanks. These assertions are supported by the national survey conducted in Senegal by the World Bank's Water and Sanitation Program (WSP), which reveals that access to water is a recurrent problem in most villages. Indeed, 40% of the respondents to this national survey did not have enough water to meet their household needs. Unprotected wells are the main source of drinking water (Swiss Tropical and Public Health Institute (Swiss TPH), 2015).
Health risks related to air pollution such as carbon monoxide poisoning, cancer and respiratory allergies are also well perceived by the respondents (96.92%, 78.46% and 96.92% respectively). However, a lack of awareness was noted on the risks related to sterility. A systematic review of the published literature on the impact of air pollution on reproductive function concluded that air pollutants cause defects during gametogenesis leading to a drop in reproductive capacities in exposed populations (Carré et al., 2017). Information and awareness campaigns on the harmful effects of pollution on reproduction, particularly infertility, premature births and low birth weight are therefore necessary.

Table 2: General knowledge about air quality

		N = 65	
		n	**%**
Perception of air quality			
General understanding of the environment	City air	13	20
	Climate	11	16,92
	Water quality	25	38,46
	Soil	2	3,08
	Living environment	10	15,38
	Natural resources	2	3,08
	Don't know	2	3,08
In the countryside the air is clean	Totally agree	62	95,38
	Somewhat agree	1	1,54
	Somewhat disagree	-	-
	Not at all in agreement	2	3,08
	Don't know	-	-
Bad odorsoutside are a sign of air pollution	Totally agree	56	86,15
	Somewhat agree	3	4,62
	Somewhat disagree	-	-
	Not at all in agreement	4	6,15
	Don't know	2	3,08
Smoke is always a sign of air pollution	Totally agree	57	87,69
	Somewhat agree	4	6,15
	Somewhat disagree	-	-

	Not at all in agreement	2	3,08
	Don't know	2	3,08
Outdoor air pollution is getting worse	Totally agree	49	75,38
	Somewhat agree	4	6,15
	Somewhat disagree	2	3,08
	Not at all in agreement	1	1,54
	Don't know	9	13,85
Indoor air degradation factors			
Tobacco smoke	Yes	63	96,92
	No	2	3,08
	Don't know	-	-
Smoke from the kitchen	Yes	60	92,31
	No	4	6,15
	Don't know	1	1,54
Burning of household waste (rubbish, tree leaves)	Yes	64	98,46
	No	-	-
	DK	1	1,54
Painting of walls and ceilings	Yes	55	84,62
	No	4	6,15
	Don't know	6	9,23
Mites (lice, bedbugs)	Yes	15	23,08
	No	7	10,77
	Don't know	43	66,15
Mould	Yes	20	30,77
	No	3	4,62
	Don't know	42	64,62
Cleaning products, aerosols	Yes	56	86,15
	No	4	6,15
	Don't know	5	7,69
Cosmetic products	Yes	53	81,54
	No	4	6,15
	Don't know	8	12,31
Pets	Yes	60	92,31
	No	3	4,62
	Don't know	2	3,08
Outdoor air	Yes	57	87,69
	No	4	6,15
	Don't know	4	6,15
Incense	Yes	61	93,85
	No	3	4,62
	Don't know	1	1,54
Health risks from air pollution			
Cancer	Yes	51	78,46
	No	7	10,77
	Don't know	7	10,77
Asthma	Yes	59	90,77
	No	4	6,15

	Don't know	2	3,08
Respiratory allergies	Yes	63	96,92
	No	-	-
	Don't know	2	3,08
Sterility	Yes	20	30,77
	No	8	12,31
	Don't know	37	56,92
Heart disease	Yes	43	66,15
	No	8	12,31
	Don't know	14	21,54
Carbon dioxide poisoning	Yes	63	96,92
	No	1	1,54
	Don't know	1	1,54
Eye disease	Yes	51	78,46
	No	3	4,62
	Don't know	11	16,92
Cough	Yes	65	100
	No	-	-
	Don't know	-	-

Attitudes and Practices to Improve Air Quality: About their attitudes and practices to improving air quality, as shown in table 3, all respondents said that they aired the house from time to time, by opening the windows, and 95.4% were ready to use a less polluting source of energy for cooking such as improved traditional stoves.

Table 3: Attitudes and Practices to Improve Air Quality

		N = 65	
Attitudes and practices		**n**	**%**
Use public transport, cycling or walking	Yes	63	96,92
	No, but willing to do it	2	3,08
	No and not willing to do so	-	-
	Don't know	-	-
Takes into account pollutant emissions when purchasing construction or decoration (paints, varnishes, etc.)	Yes	7	10,77
	No, but willing to do it	47	72,31
	No and not willing to do so	-	-
	Don't know	11	16,92
Community involvement	Yes	10	15,38
	No, but willing to do it	55	84,62
	No and not willing to do so	-	-
	Don't know	-	-
Is willing to use a less polluting energy source for cooking (improved traditional stove, gas, etc.)	Yes	62	95.4
	No	1	1.5
	Don't know	2	3.1
giving an air to the home personally from time to time, by opening the windows	At least once a day	65	100
	Less often	-	-
	Never	-	-
Pay to have a less polluting energy source for cooking (improved traditional stove, gas, etc.)	Yes	62	95.4
	No	1	1.5
	Don't know	2	3.1

Indoor air quality metrology:

Figure 1 shows the results of bivariate analysis between indoor air quality parameters and type of cooking fuel. A first analysis of the data by the Kruskal Wallis test shows overall that the levels of particulate matter, carbon monoxide and carbon dioxide are significantly influenced by the type of cooking fuel (p-value < 5%). Pairwise comparison using Dunn's post hoc test shows that households using wood had higher mean concentrations of PM_{10} and CO (respectively 4.7mg/m^3, p-value = 0.0055 and 34.333 ppm, p-value = 0.00155) compared to those using butane. A difference in means was also recorded between butane gas and charcoal regarding the emission of the same pollutants (PM_{10} = 1.455 mg/m^3, p-value = 0.0172 and CO = 36.222 ppm, p-value = 0.00083). These data are consistent with studies reporting that domestic indoor air quality levels associated with biomass burning in developing countries exceed WHO indoor air quality standards (Bartington et al., 2017; Shupler et al., 2020).

Both pollutants (PM_{10} and CO) are important signs of household air pollution and have different health and environmental impacts (Klasen et al., 2015).

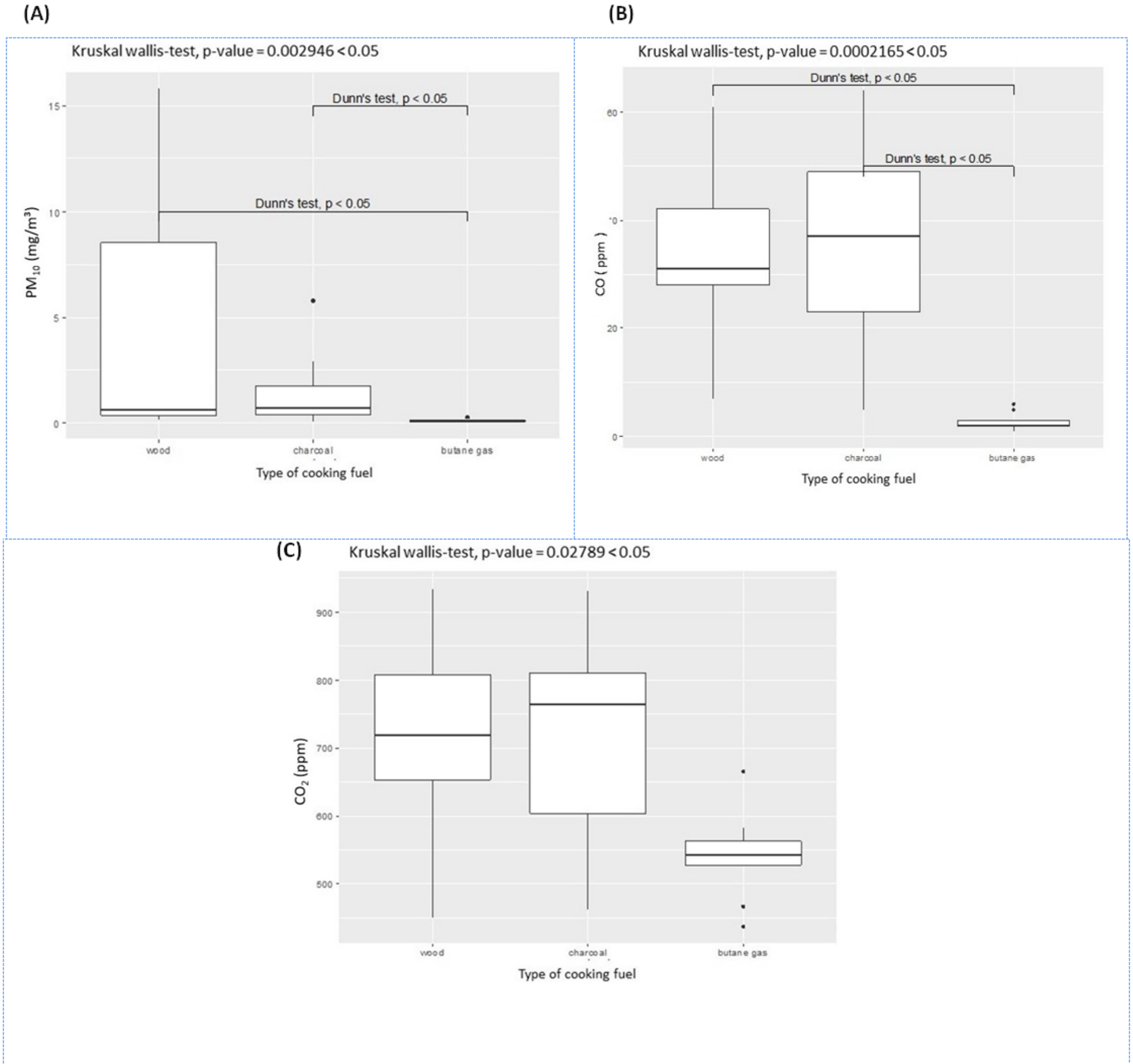

Figure 1: Distribution of PM_{10} (A), CO (B) and CO_2 (C) between wood, charcoal and butane gas. Values are expressed as median, upper and lower quartiles and range.

Our results are similar to those observed in Burkina Faso, where a statistically significant difference in mean $PM_{2.5}$ concentrations (p=0.03) between households cooking with biomass (wood and charcoal) and those cooking with gas was recorded (Kafando, Savadogo, Sana, et al., 2019). These similarities were also noted in Pakistan. The mean for daytime CO concentration was 29.4 ppm in wood users; significantly higher than 7.5

ppm in gas users ($P < 0.001$). The mean for daytime $PM_{2.5}$ concentrations was 2.74 mg/m^3 in wood users; significantly higher than 0.38 mg/m^3 in gas users ($P < 0.001$) (Siddiqui et al., 2009).

Women and young children living in households exposed to solid fuel smoke (wood, charcoal) are at greater risk of developing acute lower respiratory tract infection compared to those living in households using cleaner fuels (butane gas) or with less smoke exposure (Aboubacar et al., 2018; Ezzati & Kammen, 2001; Rumchev et al., 2007).

No significant difference was found for NO and NO_2 emissions regardless of the type of fuel. Indeed, wood or charcoal combustion would affect more particularly the concentrations of particulate matter, carbon monoxide, benzene and PAHs in indoor air (Ineris, 2018) and butane gas combustion produces mainly CO_2 but also CO in case the quantity of oxygen is not sufficient or incomplete combustion.

About the types of kitchens, the results presented in Table 4 show that PM_{10} concentrations were higher in closed kitchens (3.5 and 1.8 mg/m^3 respectively with and without windows) compared to those in open kitchens (0.3 mg/m^3). The observed carbon oxides levels were slightly higher in closed kitchens without windows (739.833 and 30.5 ppmfor CO_2 and COrespectively). As for nitrogen oxides, the highest levels were found in open kitchens (0.367 and 0.7 ppm for NO_2 and NO respectively) compared to others. However, no statistically significant difference was observed (Kruskal Wallis test p-value > 5%).

Van & al.(Ed et al., 2013) noted that concentrations of $PM_{2.5}$, air pollution indicator, were not associated with the kitchen one and were not predicted by the kitchen. However, the small size of our sample could be the reason for this lack of statistical power (Sana et al., 2020).

Table 4: Indoor air quality of households by type of kitchen.

type of kitchen	Parameters	Average	Median	Standard deviation	Minimum	Maximum
Open kitchen	PM_{10} (mg/m³)	0.345	0.35	0.233	0.03	0.731
	CO_2 (ppm)	677.667	765	185.886	450	935
	CO (ppm)	30.222	37	20.849	5	61
	NO (ppm)	0.7	0.7	0.466	0.3	1.7
	NO_2 (ppm)	0.367	0.3	0.224	0	0.8
Closed kitchen with window	PM_{10} (mg/m³)	3.535	0.367	6.136	0.038	15.802
	CO_2 (ppm)	598	582	101.939	437	765
	CO (ppm)	17.083	14.5	15.424	1	43
	NO (ppm)	0.65	0.6	0.334	0.1	1.2
	NO_2 (ppm)	0.133	0.1	0.15	0	0.4
Closed kitchen without window	PM_{10} (mg/m³)	1.833	1.01	2.255	0.092	5.813
	CO_2 (ppm)	739.833	738	158.018	563	932
	CO (ppm)	30.5	26	31.31	2	64
	NO (ppm)	0.683	0.65	0.194	0.4	0.9
	NO_2 (ppm)	0.233	0.1	0.301	0	0.7

IV. Conclusion

Because of the results, the Senegalese authorities should strengthen information and awareness campaigns on indoor air pollution and its harmful effects. The development of legislative provisions on indoor air pollution should be considered to serve as a guideline under certain conditions. Improvements in cooking and living conditions and housing are necessary. This improvement can consist in the use of improved fireplaces that have a higher thermal efficiency than traditional fireplaces, thus allowing the reduction of wood consumption and the reduction of pollutant emissions. It is also mandatory to improve the living conditions by airing the house to renew the air and thus reduce the concentration of pollutants. The use of incense, which is a source of pollution in the majority of homes in Dakar where this practice is very frequent, should be avoided.
An assessment of the respiratory health of residents exposed to biomass burning thus appears essential.

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