JCBM (2022) 5(2). 44-53

University of Cape Town

Journal of Construction Business and Management

http://journals.uct.ac.za/index.php/jcbm

A Measure of Combustion-Generated Pollutants in University Laboratories and their Effects on the Indoor Air Quality

E.I. Nkeleme[1], I. Mbamali[2] and W.M.W. Shakantu[3]

[1 & 3]Department of Construction Management, Faculty of Engineering, the Built Environment and Information Technology, Nelson Mandela Metropolitan University, South Africa.
[2]Department of Building, Ahmadu Bello University, Nigeria.

Received 30 August 2021; received in revised form 04 September 2021, 11 November 2022 and 08 December 2022; accepted 08 December 2022
https://doi.org/10.15641/jcbm.5.2.1117

Abstract

Combustion is one of the fundamental processes in learning and teaching in laboratories that leads to the release of gaseous pollutants that are both hazardous and a threat to the environment and health of individuals. This paper sought to measure the amount of combustion pollutants generated and their effects on the indoor air quality of a typical university laboratory using some selected laboratories in Ahmadu Bello University Zaria as a case study. The Combustion pollutants were measured using an IMR 1400C gas analyser. At the same time, its effects were assessed using a well-structured questionnaire designed and administered to hundred and twenty-seven laboratory users who were randomly selected. Data collected from the questionnaires were analysed using computer-based SPSS software. The results revealed that CO during combustion exceeded the ASHRAE 62 and NAAQS limit of 9ppm, reaching up to 45ppm at some points; also, oxygen was observed to be at a critical level of 20.9% and at some point falling below the limit to 20.4%. It was also observed that fatigue (RII: 0.81) is the most prominent symptom of poor indoor air quality during combustion, among other symptoms like coughing and sneezing, dryness and irritation of eyes and throat, sinus congestion, shortness of breath and headache, arranged in the order of intensity. The absence of functional fume hoods, laboratory congestion, and inadequate ventilation systems intensify the discomforting effect of combustion-generated pollutants in laboratories. Thus, it is recommended that fume hoods should be well maintained for functionality and installed in Laboratories where they do not exist (chemistry lab I). Finally, providing adequate ventilation systems in the laboratories would help increase safety in labs for learning and teaching purposes.

Keywords: Combustion Generated Pollutants, Indoor Air Quality, Measurement of Pollutants.

1. Introduction

Interest in the role of air quality in health and disease dates back to antiquity. In the treatise on "Airs, water, and places", Hippocrates drew attention to the impact of polluted air, among other transmission media, on disease burden. For centuries, the emphasis on pollution-associated air problems was mainly placed on outdoor air; concerns about indoor air quality are relatively recent in comparison (David, 2010).

The National Health and Medical Research Council (NHMRC, 2009) defines indoor air as air within a building occupied for at least one hour by people of varying states of health. This can include the office, classroom, transport facility, shopping centre, hospital, and/or home. Indoor air quality (IAQ) can be defined as the totality of attributes of indoor air that affect a person's health and well-being. Similarly, the Environmental Protection Agency (EPA) defines IAQ as the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants (USEPA, 2020)

Indoor air pollution refers to indoor air's chemical, biological and physical contaminations (NHMRC, 2009). It may result in adverse health effects. In developing countries like Nigeria, the primary source of indoor air pollution is biomass which contains suspended particulate

[1] Corresponding Author
Email address: nkebishop@gmail.com

matter like nitrogen oxide (NO2), sulphur dioxide (SO2), carbon monoxide (CO), formaldehyde, and polycyclic aromatic hydrocarbons (PAHs). However, in industrialised countries, in addition to NO2, CO and formaldehyde, radon, asbestos, mercury, human-made mineral fibres, volatile organic compounds, allergens, tobacco smoke, bacteria, and viruses are the main contributors to indoor air pollution (David, 2010).

A growing body of scientific evidence indicates that the air within homes and other buildings can be more polluted than the outdoor air in even the largest and most industrialised cities. In addition to daily human activities that lead to the generation of indoor air pollutants, combustion sources and activities, especially in laboratories, contribute to carbon dioxide (CO2), sulfur dioxide (SO2), CO, nitrogen dioxide (NO2), and particulate matter (PM) emissions into indoor air environments (Awbi, 2003).

The intrinsic nature of the health effects from indoor air pollutants is that they may be experienced soon after exposure or, possibly, years later. Immediate effects may appear after a single or repeated exposure (Tran, Park and Lee, 2020). These include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. Sometimes the treatment eliminates the person's exposure to the source of the pollution if it can be identified.

The World Health Organisation, as of 2002, estimated that indoor air pollution is responsible for roughly 1.6 million deaths each year. However, the recent update, as of 2020, shows that indoor air pollution (IAP) is responsible for the deaths of 3.8 million people annually (WHO, 2020), with its symptoms ranging from acute lower respiratory infections, chronic obstructive pulmonary disease, lung cancer, and other diseases. Indoor air pollution from biomass contributes to about 2.6 per cent of the global disease burden. Hromadka, Korposh, Partridge, James, Davis, Crump, and Tatam (2017) indicated that decreased IAQ could negatively affect human health by causing building-associated illness.

In an academic environment, laboratories are a significant place where combustion activities are mainly carried out, usually during experimental activities. According to Merriam-Webster, a laboratory is a room or building equipped for scientific research, teaching, or manufacturing drugs and chemicals. From the definition, it can be established that combustion is one of the basic processes in a laboratory. Thus, the question now is: 'how safe is the indoor air quality of such laboratories owing to the activities carried out in them? This paper measures the combustion-generated pollutants in a typical university laboratory after an experiment requiring combustion activities. It also examines the laboratory users' perception of the impact of combustion-generated pollutants on the indoor air quality of the laboratories, considering the users' length of exposure during experimental activities.

2. Literature review

The concept of indoor air pollution is a contemporary one, which has stirred up much research with the general aim of emphasising the health impact of poor indoor air and the identification of the major pollutants of indoor air. Previous studies are reviewed in this section. Saravanan (2004), in a general study of indoor air, established that the significant factors that determine indoor air quality are:

i) The nature of outdoor air quality around the building;
ii) The ventilation rate of the building;
iii) The materials used in the construction of the building (presence of chemicals);
iv) The activities that go on inside the interior (cleaning, cooking, heating, etc.); and,
v) The use of household chemicals.

Saravanan (2004) identified some of the sources of the pollutants as; radioactivity (the emissions from uranium in the soil or rocks on which the houses are built, Volatile Organic Compounds (VOCs) usually from aliphatic and aromatic compounds, chlorinated compounds with formaldehyde being in many locations). The emphasis of the sources of indoor air pollutants was on indoor combustion activities. The combustion of fuels, such as oil, gas, kerosene, and so forth, inside a building contributes to the concentration of VOCs and is also a source of stable inorganic gases. The common indoor pollutants due to the combustion of fuels are particulate matter, oxides of nitrogen, oxides of sulphur, carbon monoxide, hydrocarbons, and other odour-causing chemicals. Saravanan (2004) concluded that indoor air pollution is one of the significant problems that must be solved since a large part of human life is spent indoors. All necessary precautions to eliminate or minimise the harmful effects of indoor air pollution need to be taken.

To help elucidate more fully the extent of hazards caused by the combustion of pollutants in China, Smith and Zhang (2005) studied indoor air pollution from household fuel combustion. They estimated that air pollution from solid waste in China is responsible for 420,000 premature deaths annually, with more than 300,000 attributed to the pollution of the urban outdoor environment.

Smith and Zhang (2005) reviewed nearly 200 publications in China reporting health effects, emission characteristics, and/or indoor air pollutants concentrations associated with solid fuels. Smith and Zhang (2005) also took measurements in 122 individual studies, concluding that indoor air pollutant concentrations exceeded health standards in many households.

In like manner, Stanley (2010) assessed the environmental suitability of electric power generators for power supply to buildings to devise appropriate control measures for a cleaner environment. The assessment was for buildings within the Kaduna metropolis, and the approach adopted was the use of a well-structured questionnaire and an IMR 1400C combustion gas analyser. The research results showed that the level of awareness of health hazards caused by generators was high and that the mean concentration of SO_2 and NO_x indoors was higher than the FEPA limits (0.01 ppm and 0.04-0.06 ppm), respectively. The research also revealed that none of the ambient pollutants at the point source met the WHO and FEPA limits.

The above review itemises the contribution of various researchers in evaluating the impact of combustion activities on indoor air quality and environmental conditions. And at this point, it can be seen that combustion is a significant source of pollutants generation in the environment. Thus, this paper seeks to evaluate the impact of combustion activities in the laboratories on the indoor air quality of the laboratories.

2.1 HVAC requirements for a laboratory

Several types of research have been done into the heating, ventilation and air conditioning (HVAC) requirements for a laboratory, emphasising the energy usage common to laboratories and the comfort requirements. According to Lindsay (2010), an HVAC engineer's prime concern when planning or constructing any laboratory building is the safety of the building's occupants. The system must operate to specification and meet appropriate regulations. To this end, many older laboratories were designed with little regard for energy efficiency. That's no longer obtaining, and designers must account for operating costs and functionality (Lindsay, 2010).

A laboratory building consumes five to ten times more energy than a typical office building or school. HVAC systems consume almost 70% of a laboratory's energy. According to Labs21 (2010), a voluntary partnership program is dedicated to improving U.S. laboratories' environmental performance. The majority of this HVAC energy consumption originates from cooling (22%), and ventilation (44%) loads that help the laboratories function safely (Lindsay, 2010).

The high energy use can be attributed to high air-change requirements, large internal heat gains from laboratory equipment, and, in many cases, continuous hours of operation (Gordon, 2010). Vendors are developing new technologies or adapting older ones to help reduce HVAC energy consumption with a push toward a more energy-efficient laboratory environment. Lindsay (2010)'s emphasis was more in line with HVAC requirements for laboratories as an energy-saving measure and not on the adequacy of indoor air quality for laboratories.

3. Methodology

A measure of the amount of the combustion-generated pollutants in selected laboratories was conducted with the help of a sensitive gas analyser, the "IMR 1400C", to establish the presence and amount of the combustion pollutants present in the air before, during, and after the combustion processes. The gas analyser was used to measure and calculate the amount of the following: oxygen (O_2), carbon monoxide (CO), Carbon dioxide (CO_2), Oxides of Nitrogen (NO_x), and Sulfur dioxide (SO_2).

In addition to the measurement, a survey of laboratory users' (Staff and students) perception of the impact of combustion-generated pollutants on indoor air quality was conducted. A well-structured questionnaire was designed and administered to staff and students (laboratory users) of Ahmadu Bello University, Zaria. A total of 140 questionnaires were distributed, of which 127, representing 90.7%, were completed correctly and returned. The major issues addressed in the survey include the presence of the necessary Heating, Ventilation and Air Conditioning System; the presence and functional state of the fume hoods; and other related factors like the frequency of maintenance of the HVAC system that can influence the effects of combustion pollutants on the indoor air quality.

3.1 Data analysis procedure

The presence and the number of pollutants determined by the IMR 1400C gas Analyser were tabulated along with the acceptable limit provided by the ASHERA Standard 62 for a healthy environment. Also, most of the questionnaire questions assessed some indices of utilisation on a five (5) point Likert scale. The data analysis, therefore, employed the following steps.

a. Computation of the mean using the weighted average formula

$$\textbf{Relative importance index (RII)} = \frac{\sum fx}{\sum f} \times \frac{1}{k}$$

Where,

$\sum fx$ = is the total weight given to each attribute by the respondents.
$\sum f$ = is the total number of respondents in the sample.
K = is the highest weight on the Likert scale.

Results were classified into three categories as follows (Othman *et al*., 2005) when:

$RII<0.60$ -it indicates low frequency in use
$0.60 \leq RII<0.80$ -it indicates high frequency in use.
$RII \geq 0.80$ – it indicates a very high frequency in use.

4. Data presentation, analysis, and discussion

The results of the measurements and analysis of the questionnaires are presented in this section under two broad headings - the presentation of the combustion-generated pollutant measurement and the results of the questionnaire analysis.

4.1 Presentation of Measurements of the Combustion-Generated Pollutants

Data from the result of the measurements taken are presented in Tables 1-6

From Table 1, it can be observed that CO often exceeded the permissible limit, especially during the combustion process, rising to (45ppm against the 9ppm limit). It can also be observed that the oxygen levels were at the critical level and even a few points below the limit, increasing the tendency of incomplete combustion.

Table 2 shows that the most reoccurring pollutant that exceeds the limit is CO, especially during the combustion process rising to (45ppm). Table 2 shows the measurement of the pollutants at three different points before the combustion activities and during and after the combustion activities. The trend of rising and falling of the amount of pollutants within the interior is also presented in Table 2. These measurements are peculiar to the SBRS Lab II.

Table 3 presents the number of pollutants measured at three different points within the chemistry SBRS Lab III before, during, and after the combustion activities in the laboratory. From Table 3, it can be observed that CO is the pollutant that is constantly generated beyond the provision of the limit (9ppm) in the three different sessions of the experiments. It is observed that there was no SO pollutant recorded throughout the first session of experimentation, and there is a varying level of oxygen, usually falling below the limit.

Table 4 presents the amount of pollutants measured at three different points within the Chemistry Multi-Purpose Lab before, during, and after the combustion activities in the laboratory. From Table 4, it can be observed that CO is the pollutant that is more generated even in the three different sessions of the experiments.

Table 1: Results of the Combustion Pollutant Measurement in Chemistry Lab I along with ASHRAE Requirement and NAAQS Standard

		Chemistry Lab I									
Session	Pollutants (O_2 in % others in ppm)	Measurement 3 hours Before Combustion			Measurement During Combustion			Measurement 3 hours After Combustion			ASHRAE Acceptable Limit (O_2 in % others in ppm)
		A1	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**	
	O_2 (%)	20.90	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0.0	0.0	0.0	7	13	23	02	03	02	≤9ppm
1	**NOx**	0.0	0.0	0.0	0.0	1.0	2.0	2.0	1.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	4.2	2.1	1.0	2.1	3.2	4.2	1.0	0	0.0	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	1	0	45	23	11	09	02	07	≤9ppm
2	**NOx**	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.1	0.0	0.1	02	0.0	0.1	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	2.1	1.1	2.1	1.3	1.1	3.1	2.0	1.0	2.1	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
3	**CO**	0.0	1.0	0.0	7.0	11.0	13.0	4.0	2.0	0.0	≤9ppm
	NOx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm

Source: Field Survey (2020)

Where: A1, A2, A3, B1, B2, B3, C1, C2, and C3 are all measurement points, while 1, 2, and 3 are experiment sessions.

Table 2: Results of the Combustion Pollutant Measurement SBRS LAB II along with ASHRAE Requirement and NAAQS Standard

Session		SBRS LAB II									
	Pollutants (O_2 in% others in ppm)	Measurement 3 hours Before Combustion			Measurement During Combustion			Measurement 3 hours After Combustion			ASHRAE Acceptable Limit (O_2 in % others in ppm)
		A1	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**	
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	0	0	7	13	23	02	03	02	≤9ppm
1	**NOx**	0.0	0.0	0.0	0.0	1.0	2.0	2.0	1.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		≤ 0.14ppm
	CO_2	2.1	4.2	2.0	21.						≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	1	0	45	23	11	09	02	07	≤9ppm
2	**NOx**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2										≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
3	**CO**	0.0	0.0	0.0	0.0	13.0	14.0	11.0	0.0	0.0	≤9ppm
	NOx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	2.1	3.2	4.2	2.1	2.3	4.2	2.1	2.1	3.1	≤ 1000ppm

Source: Field Survey (2020)

Table 3: Results of the Combustion Pollutant Measurement IN SBRS LAB III along with ASHRAE Requirement and NAAQS standard

Session	**SBRS LAB III**										
	Pollutants(O_2 in% others in ppm)	Measurement 3 hours Before Combustion			Measurement During Combustion			Measurement 3 hours After Combustion			ASHRAE Acceptable Limit (O_2 in% others in ppm)
		A1	**A2**	**A3**	**B1**	B2	**B3**	**C1**	**C2**	**C3**	
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	0	0	7	13	23	02	03	02	≤9ppm
1	**NOx**	0.0	0.0	0.0	0.0	1.0	2.0	2.0	1.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	1	0	45	23	11	09	02	07	≤9ppm
2	**NOx**	2.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	1.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	1.2	3.2	2.1	3.2	6. 5	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
3	**CO**	0.0	0.0	0.0	45.0	25	13	3.0	5.0	1.0	≤9ppm
	NOx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm

Source: Field Survey (2020)

Where: A1, A2, A3, B1, B2, B3, C1, C2, and C3 are all measurement points, while 1, 2, and 3 are experiment sessions.

Table 4: Results of the Combustion Pollutant Measurement IN CHEMISTRY MULTI-PURPOSE LAB along with ASHRAE Requirement and NAAQS standard

Session	**CHEMISTRY MULTI-PURPOSE LAB**										
	Pollutants (O_2 in% others in ppm)	Measurement 3 hours Before Combustion			Measurement During Combustion			Measurement 3 hours After Combustion			ASHRAE Acceptable Limit (O_2 in% others in ppm)
		A1	**A2**	**A3**	**B1**	B2	**B3**	**C1**	**C2**	**C3**	
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	0	0	27	43	88	8	03	02	≤9ppm
1	**NOx**	0.0	0.0	0.0	0.0	1.0	2.0	2.0	1.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	4.3	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	1	0	45	23	11	09	02	07	≤9ppm
2	**NOx**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.1	0.1	2.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2										≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
3	**CO**	0.0	0.0	0.0	32.0	45	76.0	32.0	0.0	0.0	≤9ppm
	NOx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0		≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm

Source: Field Survey (2020)

Table 5: Results of the Combustion Pollutant Measurement PHYSICAL CHEMISTRY LAB Along With ASHRAE Requirement and NAAQS Standard

Session	**PHYSICAL CHEMISTRY LAB**										
	Pollutants (O_2 in% others in ppm)	Measurement 3 hours Before Combustion			Measurement During Combustion			Measurement 3 hours After Combustion			ASHRAE Acceptable Limit (O_2 in% others in ppm)
		A1	**A2**	**A3**	**B1**	B2	**B3**	**C1**	**C2**	**C3**	
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	0	0	7	13	23	02	03	02	≤9ppm
1	**NOx**	0.0	0.0	0.0	0.0	1.0	2.0	2.0	1.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	1	0	45	23	11	09	02	07	≤9ppm
2	**NOx**	0.0	0.0	0.0	0.0	1.0	2.0	2.0	1.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	≤ 0.14ppm
	CO_2	3.1	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
3	**CO**	0.0	0.0	1.0	14.0	38.0	42.0	2.1	3.2	1.2	≤9ppm
	NOx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	4.2	3.2	2.1	3.2	1.2	≤ 1000ppm

Source: Field Survey (2020)

Where: A1, A2, A3, B1, B2, B3, C1, C2, C3 are all points of measurements while 1,2,3 are sessions of experiment.

Table 6: Results of the Combustion Pollutant Measurement CHEMISTRY MASTERS STUDENT LAB along with ASHRAE Requirement and NAAQS standard

Session	**CHEMISTRY MASTERS STUDENT LAB**										
	Pollutants (O_2 in% others in ppm)	Measurement 3 hours Before Combustion			Measurement During Combustion			Measurement 3 hours After Combustion			ASHRAE Acceptable Limit (O_2 in% others in ppm)
		A1	**A2**	**A3**	**B1**	B2	**B3**	**C1**	**C2**	**C3**	
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	0	0	7	13	23	02	03	02	≤9ppm
1	**NOx**	0.0	0.0	0.0	0.0	1.0	2.0	2.0	1.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
	CO	0	1	0	45	23	11	09	02	07	≤9ppm
2	**NOx**	0.0	0.0	0.0	0.2	0.2	0.1	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	≤ 0.14ppm
	CO_2	0.0	0.0	0.0	11.0	9.0	13.0	5.0	6.0	4.0	≤ 1000ppm
	O_2 (%)	20.9	20.9	20.4	20.7	20.7	20.9	20.9	20.8	20.9	≥ 20.9%
3	**CO**	2.1	3.1	2.1	12.0	45.0	32	4.0	2.0	2.0	≤9ppm
	NOx	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	≤0.053ppm
	SO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	≤ 0.14ppm
	CO_2	1.2	2.1	2.1	3.2	4.5	32.7	2.0	4.9	3.2	≤ 1000ppm

Source: Field Survey (2020)

Table 5 presents the amount of pollutants measured at three different points within the Physical Chemistry laboratory before, during, and after the combustion activities in the laboratory. Table 5 shows that, similar to the other laboratories studied, CO is a pollutant frequently generated beyond the limit provision (9ppm). It can also be observed that the oxygen content as measured was not consistent throughout the measurement.

While Table 6 presents the amount of pollutants measured at three different points within the chemistry masters' student laboratory before, during, and after the combustion activities in the laboratory. Also, it was observed that CO is the pollutant that is more generated even in the three different sessions of the experiments.

4.2 Presentation of the Results of the Questionnaire Analysis

Data from the expert opinion survey are presented in Table 7. Table 7 shows that most respondents opined that their work entails combustion (74.0%). Also, as opined by the respondents, the gas burner is the major heat-generating device frequently used in laboratories (70.1%). Concerning the presence of a functional fume hood installed in the laboratory, most respondents (with a frequency of 47.2%) were unaware of its existence and functional status; this corresponds to 47.2% of the respondents.

Combustion and ventilation in laboratories

The respondents' perceptions concerning the impact of combustion activities in the laboratory and the evaluation of the adequacy of the ventilation system were also assessed. Table 8 below presents the results of the assessment.

Table 8 reveals that combustion is a source of discomfort, as observed by 92.1% of the respondents. Also, Table 8 shows that combustion was more discomforting of all the processes identified (54.3%). The ventilation system is inadequate, as attested to by 79.5% of the respondents.

Table 7: Laboratory combustion activities

S/N	Variable	Option	Frequency	Percentage (%)
1	Combustion in laboratories:	a) Yes	94	74.0
		b) No	33	26.0
		Total	**127**	**100**
2	Heat generating device frequently used :	a) Stove	16	12.3
		b) Gas burner	89	70.1
		c) Hot plates	22	17.3
		d) Candle	0	0
		Total	**127**	**100**
3	Presence of functional fume hood:	a) Yes	40	31.5
		b) No	27	21.3
		c) Not Aware	60	47.2
		Total	**127**	**100**

Source: Field survey (2020)

Table 8: Combustion and ventilation in laboratories

S/N	Variable	Option	Frequency	Percentage (%)
1	Combustion as a source of discomfort:	a) Yes	117	92.1
		b) No	10	7.9
		Total	**127**	**100**
2	The process that poses more discomfort:	a) Combustion	69	54.3
		b) Filtration	0	0
		c) Lab cleaning	58	45.7
		d) Distillation	0	0
		Total	**127**	**100**
3	Presence of ventilation system:	e) Yes	40	31.5
		f) No	87	68.5
		Total	**127**	**100**
4	Adequacy of ventilation system during combustion:	a) Yes	26	20.5
		b) No	101	79.5
		Total	**127**	**100**

Source: Field survey (2020)

Table 9: Ranking of the health symptoms of poor indoor air quality

Symptoms	Weighting/Response Frequency 1	2	3	4	5	(∑f)	∑fx	MEAN	RII	RANK
Dryness and irritation	-	16	8	86	17	127	485	3.82	0.76	3RD
Headache	11	10	20	66	20	127	455	3.58	0.72	8TH
Fatigue	-	3	15	80	29	127	516	4.07	0.81	1ST
Shortness of breath	-	23	26	50	28	127	464	3.65	0.73	6TH
Hypersensitivity and allergies	14	07	28	78	3	127	439	3.46	0.69	10TH
Sinus congestion	10	08	02	90	17	127	477	3.76	0.75	4TH
Coughing and sneezing	03	17	-	82	25	127	490	3.85	0.77	2ND
Dizziness	15	10	12	74	16	127	447	3.52	0.70	9TH
Nausea	8	17	34	63	05	127	421	3.31	0.66	13TH
Blurred vision	16	02	22	57	30	127	464	3.65	0.73	6TH
Pains and discomfort	06	17	22	78	04	127	438	3.45	0.69	10TH
Heartburn	10	29	04	67	17	127	433	3.41	0.68	12TH
Sneezing and chest tightness	02	26	07	68	24	127	467	3.68	0.74	5TH
Fainting	29	60	22	07	09	127	288	2.27	0.45	14TH

Source: Field Survey, (2020)
Where: 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree

Table 10: HVAC and Combustion Related

Causes	Weighting/Response Frequency 1	2	3	4	5	(∑f)	∑fx	Mean	RII	Rank
Overcrowding in labs	-	-	07	40	80	127	581	4.57	0.91	1ST
Combustion activities	-	-	02	73	52	127	558	4.39	0.89	2ND
Inadequate ventilation	-	10	06	67	44	127	526	4.14	0.83	3RD
Prolonged and reoccurring combustion	05	20	12	58	30	127	463	3.65	0.73	4TH
Non-functional fume hoods	12	13	12	68	22	127	456	3.59	0.72	5TH
Too humid air	03	26	70	28	-	127	377	2.97	0.59	6TH
Faulty burners	04	40	62	21	-	127	354	2.79	0.56	7TH
Poor air Movement	-	54	67	06	-	127	333	2.62	0.52	8TH
Unvented combustion equipment	58	20	13	27	09	127	290	2.29	0.46	9TH

Source: Field survey (2020)
Where: 1= not a cause, 2 = not a major cause, 3 = barely a cause, 4 = a cause, 5 = always a cause

Table 11: Remedy to poor indoor air quality

Remedy	Weighting/response frequency 1	2	3	4	5	(∑f)	∑fx	MEAN	RII	RANK
Provision of adequate HVAC system	07	-	10	32	78	127	555	4.37	0.87	1st
Use and maintenance of functional fume hoods	14	-	15	40	58	127	509	4.00	0.80	3rd
Adequate airflow during combustion	-	13	14	28	72	127	540	4.25	0.85	2nd
Use of excellent combustion equipment	14	-	21	32	60	127	505	3.98	0.79	4th
Orientation of both staff and students on the danger of poor indoor air quality	32	-	9	28	58	127	461	3.63	0.73	5th

Source: Field Survey (2020)
Where: 1 = not Effective, 2 = no effect, 3 = slightly effective, 4 = Effective, 5 = very effective

Health symptoms of poor indoor air quality

Several health symptoms of poor indoor air quality were assessed, and the respondents ranked these symptoms. Table 9 presents the ranking of the various health symptoms that serve as indicators of poor indoor air quality.

Table 9 shows that the respondents ranked fatigue (with RII= 0.81) as the most reoccurring health symptom. Also, it is observed that only symptoms like fainting and nausea had a relative importance index of less than 0.6, indicating that they are not commonly observed symptoms. Also, from the mean values, it can be deduced that the values were closer to the Likert weighting of four, indicating that the respondents' general opinion was that the symptoms indicated poor indoor air quality.

HVAC and combustion-related factors that alter laboratories' indoor air quality

The questionnaire also sought the opinion of the respondents concerning how the heating, ventilation and air conditioning (HVAC) system, as well as combustion, contribute to the poor indoor air quality of laboratories. The respondents' opinions and ranking thereof are presented in Table 10.

Table 10 shows that overcrowding in labs (RII=0.91) was ranked the first cause of poor indoor air quality. This is followed closely by combustion activities (RII=0.89). It can also be seen that other factors, such as faulty burners, too-humid air, and unvented combustion, though factors, did not have an intense effect owing to their relative importance indexes (RII), which are below 0.6. Regarding the mean, it can be observed that the values were closer to the weighting four (4), indicating that the respondents' opinion was that the identified factors are all causes of poor indoor air quality.

4.3 Remedial action to poor indoor air quality in laboratories

Table 11 gives the respondents' ranking of the various remedial measures for the poor indoor air quality identified. It also provides the percentage with response per option and the mean.

Table 11 shows that the respondents' highest-ranked remedy to the poor indoor air quality is the provision of adequate heating, ventilation and air conditioning systems (RII= 0.87). Also, from the mean values, it can be observed that, in general, the respondents opined that the identified remedy were all feasible options as the mean value is closer to the Likert weighting of four.

4.4 Discussion of Results

The discussions are based on the experimental survey of the laboratories under study. The study revealed that combustion-generated indoor air pollutants in the laboratory were more CO and NOx (Table 4); the mean value of SO was within the normal range as specified by the ASHRAE 62 and within the requirements for WHO and FEMA limits. However, the limit for pollutants like CO was above the limit specified by this standard, thus making exposure to such gaseous pollutants very hazardous to the health of both the students and the staff. Results of the measure (Tables 1 to 4) reveal that during the combustion activities, the amount of CO increases far beyond the NAAQS standard of 9ppm for all the labs except the Master's lab, where a water bath is used as a source of heat generation as against others that used gas burners. Also, from the result, it can be observed that the multi-purpose chemistry lab had the highest amount of pollutants owing to the population of students and the non-functional fume hoods. Also, from the experimental results, it can be established that the laboratory oxygen level was at the critical limit (20.9%), with the value dropping at specific points. This can account for the incomplete combustion leading to the massive generation of CO (up to 45ppm), which is far beyond the limit (9ppm).

5. Conclusions and Recommendations

The following can be concluded from the results of the experimental work and questionnaire survey undertaken in the research. The major reoccurring pollutant during combustion activities exceeds ASHRAE provision for a working area in CO. To a large extent, other pollutants are present but at a bearable level. Carbon monoxide is dangerous because it inhibits the blood's ability to carry oxygen to vital organs such as the heart and brain. Inhaled CO combines with the oxygen-carrying haemoglobin of the blood and forms carboxyhemoglobin (COHb) which is unusable for transporting oxygen. Combustion activities are practically unavoidable in teaching and learning practical science courses. The primary source of heat for the combustion activities is the gas burner, except in a few cases of a limited gas supply when the water bath is used as an alternative heat generating source.

Fatigue is one of the most reoccurring health symptoms of poor indoor air quality due to combustion activities. However, other health symptoms are headache, dryness and irritation, sinus congestion, blurred vision, sneezing, and chest pain.

The study recommends that Lab managers should pay proper attention to maintaining the laboratories' Heating, Ventilation, and Air Conditioning (HVAC) systems, particularly the fume hoods. It is also recommended that a fume hood be installed in the laboratories without the fume hoods, such as Chemistry Lab I, where there are no fume hoods. This is to take care of the gaseous pollutants from combustion activities.

As a matter of urgency, the school authority should try and construct new laboratories to address the overcrowding challenges in the laboratories that have intensified the effect of combustion activities which in turn affect the indoor air quality. This would also help accommodate the learning and teaching of the students

References

American Lung Association., 1992. *Indoor Air Pollution Fact Sheet - Combustion Products*. Publication No. 1182C. Pp 37.

ASHRAE, 1989. *Standard 62-1989, Ventilation for Acceptable Indoor Air Quality.* Atlanta: ASHRAE.

ASHRAE, 1992. *Standard 55-1992, Thermal Environmental Conditions for Human Occupancy*. Atlanta: ASHRAE.

ASHRAE, 2004. *Standard 55-2004, Thermal Environmental Conditions for Human Occupancy*. Atlanta: ASHRAE

ASHRAE, 2010. *Standard 62.2-2010, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. Atlanta: ASHRAE

Awbi, H.B., 2003. Ventilation of Buildings; Natural gas home appliances. Environ. Sci. Technol. 27:2736-2744. Spon Press: London, UK.

David, H. M., 2010. Building Code and Indoor air quality. U.S Environment Protection Agency Office of Radiation and Indoor Environment Division.

Environmental Protection Agency, 2009). EPA 402/K-07/008 www.epa.gov/iaq/schools. Retrieved 26th January 2013

Hromadka, J., Korposh, S., Partridge, M.C., James, S.W., Davis, F., Crump, D. and Tatam, R.P., 2017. Multi-parameter measurements using optical fiber long-period gratings for indoor air quality monitoring. Sens. Actuat. B Chem. 244: 217–225.

Jarvis D., S. Chinn, Luczynska, C. and Burney, P., 1998. The association of respiratory symptoms and lung function with the use of gas for cooking. Eur Respir J 11: 651-8.

Mudarri, D. and Fisk, W.J., 2007. Public Health and Economic Impact of Dampness and Mold. Indoor Air 17:226-235. NFPA. 2012. NFPA Standard 101-2012, Life Safety Code. Quincy: National Fire Protection Agency.

NFPA., 2010. NFPA Standard 501-2010, Manufactured Housing. Quincy: National Fire Protection Agency.

NYSDH., 2000. Supplemental Space Heaters. Albany: New York State Department of Health, http://www.health.ny.gov/publications/3104.pdf. (Accessed January 2012).

Olopade, S., 2010. Fighting Indoor Air pollution, Global Health, Lung, and Public Health.

Raub, J.A. and Grant, L.D., 1989. Critical health issues associated with the review of the scientific criteria for carbon monoxide. Presented at the 82nd Annual Meeting of the Air Waste Management Association. June 25-30. Anaheim, CA. Paper No. 89.54.1, Used with permission.

Samet, J.M. and Spengler, J.D. eds., 1991. *Indoor Air Pollution - A Health Perspective*. Johns Hopkins University Press, Baltimore, MD.

Savanan, N.P., 2004. Indoor Air Pollution Danger at Home General Article Safety Engineering Division High Energy Materials Research laboratory Sutarwadi, Pashan Pune 411 021, India.

Stanley, A M., 2010. Air pollutants concentration and noise level from Electric Power Generators, PhD dissertation. Department of Building, A.B.U Zaria.

U.S. Environmental Protection Agency, 1992. EPA Indoor Environmental Quality Survey. OMB No. 2060-0244.

U.S. Environmental Protection Agency, 1993. Review of the National Ambient Air Quality Standards for Sulfur Oxides: Updated Assessment of Scientific and Technical Information; Supplement to the 1986 Staff Paper Addendum.

USEPA, 2020. Introduction to Indoor Air Quality. Available online: https://www.epa.gov/indoor-air-quality-iaq/ introduction-indoor-air-quality (Accessed: 12 February 2021).

Tran, V.V., Park, D. and Lee, Y.C., 2020. Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality. *International Journal of Environmental Research and Public Health*, 17(8): 2927.

Wadden, R.A. and Scheff, P.A., 1983. *Indoor Air Pollution - Characterisation, Prediction, and Control*. John Wiley and Sons, Inc. New York.

WHO, 2020. Household Air Pollution and Health. Available online: https://www.who.int/en/news-room/factsheets/detail/household-air-pollution-and-health. (Accessed: 28 January 2020).

Zhang, J. and Smith, K. R., 2005. *Indoor Air Pollution from Household Fuel Combustion In China The* 10th International Conference on Indoor Air Quality and Climate September 4-9, Beijing.