AN ASSESSMENT OF THE INFLUENCE OF COMBUSTION GENERATED POLLUTANTS ON THE INDOOR AIR QUALITY OF SELECTED LABORATORIES IN AHMADU BELLO UNIVERSITY ZARIA

BY

NKELEME IFEANYICHUKWU EMMANUEL

A Thesis Submitted to the School of Post Graduate Studies, Ahmadu Bello University, Zaria In partial Fulfillment of the requirement for the Award of Masters Degree in Building Service.

Department Of Building,

Faculty of Environmental Design

Ahmadu Bello University Zaria

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DECLARATION

I hereby declare that the Thesis titled "An Assessment of the Influence of Combustion Generated Pollutants on the Indoor Air Quality of Selected Laboratories in Ahmadu Bello University Zaria" was performed by me 'Nkeleme Ifeanyichukwu Emmanuel (Msc/Env-Design/1395/2011-2012)' under the supervision of Professor I Mbamali and Dr A M Stanley

The information derived from the literatures has been duly acknowledged in the text and in a list of references provided. No part of this work has been presented for another degree or diploma in any institution

……. …….

Nkeleme Ifeanyichukwu Emmanuel Date

CERTIFICATION

This project work entitled "An Assessment Of The Influence Of Combustion Generated Pollutants On The Indoor Air Quality Of Selected Laboratories In Ahmadu Bello University Zaria" by Nkeleme Ifeanyichukwu Emmanuel meets the regulation governing the award of a Masters Degree in Building Services (Msc Building Services) of Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

……..... **…….**

Prof I Mbamali **Date**

(Major Supervisor)

…….. **……..**

Dr A M Stanley **Date**

(Minor Supervisor)

…….. **……**

Prof Kabir Bala **Date**

(Head of Department)

DEDICATION

This projected is dedicated to the ALMIGHTY GOD whose infinite mercies have kept me thus far. Indeed I have come to realize that He alone is the 'All Knowing', 'Ever Present', 'Adorable', 'Awesome God', The Epitome, Genesis and the Revelation Of all Wisdom'.

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ABSTRACT

Health threats in a learning environment can jeopardize the entire effort of teaching and learning. One of such health threats is the presence of hazardous gaseous elements within the interior either as a result of learning processes or from the external environment. Combustion is one of the basic process that is employed in the learning and teaching in the laboratory that leads to the release of some gaseous pollutants that are hazardous. This research assessed the influence of combustion generated pollutants on the indoor air quality of selected laboratories in Ahmadu Bello University Zaria, with a view of: estimating the amount of combustion pollutant generated; assess the impact of this pollutant on the indoor air as well as recommend measure to be adopted to improve the indoor air quality of the environment. It was effected, by means of literature review and field survey entailing the use of an IMR 1400C gas analyzer, a well structured questionnaire and a checklist. Combustion pollutants were measured and the response from the questionnaire analyzed using computer software (SPSS). From the result of the pollutant measured, it is established that CO during combustion exceeded the ASHREA 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 to20.4%. Similarly, it was established that fatigue is the most prominent symptom of poor indoor air quality during combustion among other symptoms like; sinus congestion, headache and sneezing. It was also established that combustion is a major contributor to poor indoor air quality in laborites especially in the absence of functional fume hoods, congestion in laboratories and inadequate ventilation system. Hence, It is recommended that; fume hoods should be well maintained for functionality and installed where it does not exist like the 'chemistry lab I', provision of adequate ventilation systems in the laboratories and the construction of new laboratories to accommodate the student enrolled without congestion in the laboratories during combustion.

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LIST OF ABBREVIATIONS

ANSI - American National Standard Institute

ASHRAE –American Society of Heating, Refrigeration and Air Conditioning Engineers

COSHH- Control of Substance Hazardous To Health Regulations

CPSC- Costumer Product Safety Commission

EPA- Environmental Protection Agency

HVAC – Heating, Ventilation and Air Conditioning System

IAQ- Indoor Air Quality

MMWR- Morbidity and Mortality Weekly Report

NAAQS- National ambient Air Quality Standard

NFPA- National Fire Protection Association

NHMRC- National Health and Medical Research Council

SBRS- School of Basic and Remedial Studies

SPSS- Statistical Package for Social Sciences

WHO- World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Interests in the role of air quality in health and disease date back to antiquity. Hippocrates in his treatise on “Airs, water and places” 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 fairly recent in comparison (David, 2010).

In the United Kingdom, indoor air quality awareness, as cited by Leslie (2000), was stimulated by the introduction of the Clean Air Act of 1956. Indoor air quality is influenced by factors such as building materials, paints, ventilation system, heating system, carpeting, fabrics, volatile cleaning fluids, solvents, cooking, use of fossil fuel, personal care products, household pets etc., all of which contribute to the mix of biological and chemical aerosols in the air Outdoor air source also contribute to the indoor air milieu (Olopade, 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 home. Indoor air quality can be defined as the totality of attributes of indoor air that affect a person's health and well being.

Bioaerosols could be bacteria, viruses, fungi, algae, protozoa, house dust mites, scales from shed human skin, pets and human. The growth and dispersion of the microbial component is enhanced by the warm microclimate obtained in efficiently warmed

homes, offices and schools. Air-conditioning and ventilation systems can serve as growth media for bacteria, viruses and moulds, as well as recycling module for dust, fibers, and allergens (David, 2010).

Indoor air pollution refers to chemical, biological and physical contaminations of indoor air. (NHMRC, 2009). It may result in adverse health effect. In developing countries like Nigeria, the main source of indoor air pollution is biomass (e.g wood, agricultural products) which contains suspended particulate matter like nitrogen oxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) formaldehyde and polycyclic aromatic hydrocarbons (PAHs). However in industrialized countries, in addition to NO_2, CO and formaldehyde, radon, asbestos, mercury, human-made mineral fibers, volatile organic compounds, allergens, tobacco smoke, bacteria and viruses are the main contributors to indoor air pollution. (David, 2010).

In the last several years, a growing body of scientific evidence has indicated that the air within homes and other buildings can be more seriously polluted than the outdoor air in even the largest and most industrialized cities. Other research indicates that people spend approximately 90 percent of their time indoors. Thus, for many people, the risks to health may be greater due to exposure to air pollution indoors than outdoors (Hodgson, et al. 1986). Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later. Immediate effects may show up after a single exposure or repeated exposures. 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 is simply eliminating the person's exposure to the source of the pollution, if it can be identified. Symptoms of some diseases, including asthma,

hypersensitivity pneumonitis, and humidifier fever, may also show up soon after exposure to some indoor air pollutants.

The likelihood of immediate reactions to indoor air pollutants depends on several factors. Age and preexisting medical conditions are two important influences. In other cases, whether a person reacts to a pollutant depends on individual sensitivity, which varies tremendously from person to person. Some people can become sensitized to biological pollutants after repeated exposures, and it appears that some people can become sensitized to chemical pollutants as well.

The World Health Organization estimates that indoor air pollution is responsible for roughly 1.6 million deaths each year, from acute lower respiratory infections, chronic obstructive pulmonary disease, lung cancer, and other diseases. Indoor pollution from biomass contributes to about 2.6 percent of the global burden of disease, actually kills more people every year than HIV and maybe even malaria, and yet nobody knows about it. Thus, "if we can accomplish bringing sensitive or pay attention to this problem, and use it to influence policy and help people who are poor and would otherwise have no opportunity to have more efficient stoves, it will be very delighteful." (Olopade, 2009).

The first-ever country-by-country estimates of the burden of disease due to indoor air pollution highlight the heavy toll solid fuel use takes on the health and well-being of people around the world. The countries most affected are Afghanistan, Angola, Benin, Burkina Faso, Burundi, Cameroon, Chad, the Democratic Republic of the Congo, Eritrea, Ethiopia, Madagascar, Malawi, Mali, Mauritania, Niger, Pakistan, Rwanda, Senegal, Sierra Leone, Togo and Uganda. In 11 countries -- Afghanistan, Angola, Bangladesh,

Burkina Faso, China, the Democratic Republic of the Congo, Ethiopia, India, Nigeria, Pakistan and the United Republic of Tanzania -- indoor air pollution is to blame for a total of 1.2 million deaths a year. Globally, reliance on solid fuels is one of the 10 most important threats to public health (Gold, 1992).

In an academic environment, laboratories happen to be a major place where combustion activities are mostly carried out usually in carrying out experiments. According to the Merriam-Webster, a laboratory was defined as 'a room or building equipped for scientific research, or teaching, or for the manufacture of drugs and chemicals'. From the definition it can be established that combustion is one of the basic process in a laboratory. Thus the question now is: 'how save is the indoor air quality of such laboratories owing to the activities carried out in them?

1.2 STATEMENT OF RESEARCH PROBLEM

Exposure to indoor air pollution from solid fuels has been linked to many diseases, the health threat posed by this fuel sources and biomass is generated mostly when they are subjected to combustion. (Olopade, 2009). Combustion activities in the laboratory produce gases such as; CO, CO_2 NO_2, and NO, which are poisonous to human health. The maximum permissible concentration levels of the gases are stated in ASHRAE Standard 62 and there are no records of existing empirical studies on the actual concentration levels in the laboratories under study. The study therefore, seeks to establish the presence and concentration levels of the pollutants in the laboratories due to combustion activities. In line with this, the following research questions are formulated.

i) What is the HVAC status of the laboratories?

ii) Do combustion pollutants exist in the indoor air during combustion in the laboratories and in what quantity?

iii) Do the combustion pollutant exist in quantities that exceed limits prescribed by Standards (ASHRAE and NAAQS), for a healthy working Indoor Air Quality?

iv) The influence of the existence of combustion pollutants on the indoor air quality?

In answering these questions, some, of the issues relating the influence of combustion generated pollutant on the indoor air quality of laboratories will be better understood.

1.3 SIGNIFICANCE OF THE STUDY

This research will be of importance to both the staff and students prone to the use of laboratory because on completion, awareness will be created on the resultant effects of the combustion activities within the laboratories on the indoor air quality. Thus, the content of this research work also stands to be beneficial to government agencies like; Control of Substance Hazardous To Health Regulations (COSHH), World Health Organization (WHO) and other health organization in their ongoing campaign to create awareness on the dangerous effects of poor indoor air quality (Olopade, 2010).

In like manner, it will draw the attention of the school authority with factual data on the need for a healthier working environment for both staff and student.The research will also help building designers to adhere to the criteria for Heating Ventilation and Air Condition (HVAC) system in the design of buildings especially in the design of

laboratories and also emphasis the need for adequate maintenance of the HVAC system in buildings.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

The aim of this research is to assess the influence of combustion generated air pollutants on the indoor air quality of laboratories

1.4.2 Objectives

The objectives are;

i. To study the concept and criteria for ventilations of buildings especially laboratories
ii. Identify the HVAC system requirement for laboratories.
iii. Estimate the amount of combustion generated air pollutants in the selected laboratories
iv. To assess the impact of the pollutants on the indoor air quality
v. To recommend measures for improving the indoor air quality in the laboratories where such pollutants are present.

1.5 METHODOLOGY

In order to achieve the objective of the research work, the following research method will be adopted:

a) Field Survey: a field survey of the laboratories guided by the use of a checklist to establish if the laboratory HVAC provisions tallies with the requirement for

adequate ventilation for a workplace in accordance with the provisions of the Control of Substances Hazardous to Health (COSHH) policy of 2002

b) Research Instrument: a well structured questionnaire will be employed and administered to students and staff to ascertain their perception of the indoor air quality in the laboratories. The sampling technique to be adopted in the distribution of the question will be a random sampling technique giving both staff and student using the laboratories equal opportunity to express their perceptions

c) **Experimentation**: the use of an air combustion pollutants detector will be employed to establish the presence of such pollutants as well as the percentage existence within the interior.

The combustion pollutants of interest are carbon monoxide CO, nitrogen dioxide NO_2, Sulphur dioxide SO_2, nitric oxide NO, formaldehyde HCHO and carbon dioxide CO_2 . The pollutants will be measured with the aid of IMR 1400 gas analyzer.

The IMR 1400C gas analyzer will be used to measure the pollutant, it is a high quality combustion gas analyzer using the latest sensor technology; is easy to use and will measure all the important pollutants of interest in this research work.

1.6 SCOPE AND LIMITATION

1.6.1 Scope

The scope of this research work is confined to the indoor air quality and not the entire indoor environmental quality. Also the research focuses on just the air pollutants generated from combustion activities and not to the entire indoor pollutants. The research also studies only the effects of the combustion pollutants on the indoor air quality of only some selected wet laboratories (laboratories in the Faculty of Sciences only). Laboratories in other faculties are not in the study.

1.6.2 Limitation

The experimental value of this research is limited to the accuracy of the IMR 1400C gas analyzer adopted for the measurement of the combustion generated pollutants in the laboratories. Also, the response of the targeted population will be based on their perceptions on how the presence of the combustion pollutants appeals to their sense(s).

CHAPTER TWO

LITERATURE REVIEW

2.1 THE CONCEPT OF INDOOR AIR QUALITY AND A SCHOOL ENVIRONMENT

Most people are aware that outdoor air pollution can impact their health, but indoor air pollution can also have significant and harmful health effects. The U.S. Environmental Protection Agency (EPA) studies of human exposure to air pollutants indicate that indoor levels of pollutants may be two to five times and occasionally more than 100 times higher than outdoor levels. These levels of indoor air pollutants are of particular concern because most people spend about 90 percent of their time indoors. The following are the attribute of a good indoor air quality (IAQ) management:

i. Control of airborne pollutants;

ii. Introduction and distribution of adequate outdoor air; and

iii. Maintenance of acceptable temperature and relative humidity.

Good Indoor Air Quality (IAQ) contributes to a favorable environment for students, performance of teachers and staff, and a sense of comfort, health, and well-being. These elements combine to assist a school in its core mission educating people (U.S. Environmental Protection Agency, 2009)

2.1.1 Importance of a Good Indoor Air Quality

In recent years, comparative risk studies performed by EPA and its Science Advisory Board (SAB) have consistently ranked indoor air pollution among the top five environmental risks to public health (David, 2010). Good IAQ is an important component of a healthy indoor environment, and can help schools reach their primary goal of educating people. Failure to prevent or respond promptly to IAQ problems can:

a) Increase long and short-term health problems for students and staff (such as cough, eye irritation, headache, allergic reactions, and, in raer cases, life-threatening conditions such as Legionnaire's disease, or carbon monoxide poisoning) can all be cause owing to exposure to combustion pollutants

b) Aggravate asthma and other respiratory illnesses. Nearly 1 in 13 people of school-age has asthma, the leading cause of school absenteeism due to chronic illness. There is substantial evidence that indoor environmental exposure to allergens, such as dust mites, pests, and molds, plays a role in triggering asthma symptoms. These allergens are common in schools. There is also evidence that exposure to diesel exhaust from school buses and other vehicles exacerbates asthma and allergies. These problems can:

i. Impact student attendance, comfort, and performance.

ii. Reduce teacher and staff performance.

iii. Accelerate the deterioration and reduce the efficiency of the school's physical plant and equipment.

iv. Increase potential for school closings or relocation of occupants.

v. Strain relationships among school administration, parents, and staff.

vi. Create negative publicity.

vii. Impact community trust.

viii. Create liability problems.

Indoor air problems can be subtle and do not always produce easily recognized impacts on health, well-being, or the physical plant. Symptoms, such as headache, fatigue, shortness of breath, sinus congestion, coughing, sneezing, dizziness, nausea, and irritation of the eye, nose, throat and skin, are not necessarily due to air quality deficiencies, but may also be caused by other factors poor lighting, stress, noise, and more. Due to varying sensitivities among school occupants, IAQ problems may affect a group of people or just one individual. In addition, IAQ problems may affect people in different ways (U.S. Environmental Protection Agency, 2009)

Individuals that may be particularly susceptible to effects of indoor air contaminants include, but are not limited to, people with:

i. Asthma, allergies, or chemical sensitivities;

ii. Respiratory diseases;

iii. Suppressed immune systems (due to radiation, chemotherapy, or disease); and

iv. Contact lenses.

Certain groups of people may be particularly vulnerable to exposures of certain pollutants or pollutants mixtures. For example:

i. People with heart disease may be more adversely affected by exposure to carbon monoxide than healthy individuals. (Gold, 1992).

ii. People exposed to significant levels of nitrogen dioxide are at higher risk for respiratory infections.

In addition, the developing bodies of people might be more susceptible to environmental exposures than those of adults. People breathe more air, eat more food, and drink more liquid in proportion to their body weight than adults. Therefore, air quality in schools is of particular concern. Proper maintenance of indoor air is more than a "quality" issue; it encompasses safety and stewardship of your investment in students, staff, and facilities (U.S. Environmental Protection Agency, 2009)

2.1.2 Unique Aspects of Schools that Call for a Good Indoor Air Quality

Unlike other buildings, managing schools involves the combined responsibility for public funds and child safety issues. These can instigate strong reactions from concerned parents and the general community. Many of good Indoor Air Quality that is unique to schools:

i. Occupants are close together, with the typical school having approximately four times as many occupants as office buildings for the same amount of floor space.

ii. Budgets are tight, with maintenance often receiving the largest cut during budget reductions.

iii. The presence of a variety of pollutants sources, including art and science supplies, industrial and vocational arts, home economic classes, and gyms.

iv. A large number of heating, ventilating, and air-conditioning equipment place an added strain on maintenance staff.

v. Concentrated diesel exhausts exposure due to school buses. (Students, staff, and vehicles congregate at the same places at the same time of day, increasing exposure to vehicle emissions.) Long, daily school bus rides may contribute to elevated exposure to diesel exhaust for many students.

vi. As schools add space, the operation and maintenance of each addition are often different.

vii. Schools sometimes use rooms, portable classrooms, or buildings that were not originally designed to service the unique requirements of schools.

2.2 ASHRAE STANDARD 62 SPECIFICATION FOR INDOOR AIR QUALITY

ASHRAE Standard 62 provides basic equipment and system requirements and minimum ventilation rates which are expected to result in indoor air quality "acceptable" to human occupants. The standard is based on the meaning and purpose of the various provisions and its implementation is intended to help minimize adverse health effects. As a "peer-generated and -reviewed" standard, it establishes the IAQ-related standard of care for the design, construction, startup, operation, and maintenance of ventilation systems in buildings.

2.2.1 Fundamentals of Good Indoor Air Quality

Acceptable indoor air quality (IAQ) is typically not achieved by addressing any one specific building product, system, or procedure. Rather, it is the result of careful attention to each of the following fundamental elements:

i. contaminant source control

ii. proper ventilation

iii. humidity management

iv. adequate filtration

Careful attention to each of these fundamentals during the design and construction of the building and HVAC system, followed by proper operation and maintenance throughout the life of the building, can significantly reduce the risk of IAQ-related problems. (Samet, 1991).

2.2.2 Contaminant Source Control

Controlling the source of contaminants is fundamental to any IAQ strategy. Today, microbial contamination, in the form of mold and mildew, is a major indoor pollutant, but it certainly is not the only source. Indoor contamination can also be in the form of particles or chemicals.

They may come from building occupants and their activities, be emitted from furnishings and wall coverings, or be brought into the building with the intake air from outdoors. Controlling these contaminants at the source is typically a much more cost-

effective strategy than filtering or diluting them once they are inside the building.(Gergan, 1992).

2.2.4 Indoor Sources

Contamination can originate inside the building or be brought in from outdoors. The most obvious indoor-generated contaminants are those created by the activities of the building occupants, such as cooking, smoking, photocopying, laser printing, and other processes.

To address controlling these types of indoor contaminants, ASHRAE Standard 62-2001 states:

"Contaminants from stationary local sources within the space shall be controlled by collection and removal as close to the source as practical." (Section 5.6).

"Removal close to the source" refers to local exhaust, but local exhaust is not always possible, as in the case of volatile organic compounds (VOCs). VOCs are chemicals, such as formaldehyde, that outgas slowly from manufactured construction materials, furnishings, and cleaning products. All modern buildings contain VOCs. Low levels of VOCs originate from many different locations within the building, making local exhaust at the source difficult. In this situation, dilution with clean outdoor air is typically the most practical and cost-effective solution (Francisco et'el. 2010)

Microbial contamination (fungi and bacteria) can also be a major source of indoor contamination. Microbiological colonies can grow in or on various building elements and furnishings, including carpets, ceilings, sheetrock walls, and within the HVAC system.When mold spores and other microbiological particles become airborne, some building occupants may experience allergic reactions and other health-related

effects. Once the mold is established, the air-handling system can distribute the contaminants and offensive odors throughout the building. Because of the variety of potential indoor sources of microbial and fungal contamination, source control using local exhaust also can be difficult.

What can be done to reduce the potential for microbial growth inside buildings? Proper selection and specification of building materials and HVAC equipment are key places to start. ASHRAE Standard 62-2001 cites three specific air-handling equipment characteristics that significantly reduce the likelihood of the HVAC system becoming a source of microbial contamination: sloped drain pans, cleanable interior surfaces, and accessibility. ASHRAE Standard 62(2001)

2.3 INDOOR AIR POLLUTION

According to the US Environmental Protection Agency (EPA), indoor air pollution is defined as, "Chemical, physical, or biological contaminants in indoor air." While the EPA does not distinguish between types of indoor air pollutants, pollution may be either short term or long term, and various pollutants cause a number of different health effects. A number of pollutants can affect indoor air; some more common pollutants include smoke, asbestos, fossil fuels, cleaning and hobby products, radon, pesticides and even mold. In addition, outside pollutants may enter a home through windows, doors, air conditioners and natural ventilation.

2.3.1 Categories of Indoor Air Pollutants

Although there are numerous indoor air pollutants that spread through the home, the office, schools and other public structures, they typically fall into three basic

categories. Particles, gaseous and odor-causing pollutants, and biological contaminants are the most common indoor air pollutants categories. It's within these that individual contaminants are first identified and then classified. (Lipsett, 1992).

A Particles

The problem with indoor air pollutants is that most are invisible to the eye. This is especially true in the case of particle pollutants. Because the eye detects only particles that are about 30 microns in size, approximately 99 percent of indoor pollutants are almost undetectable. These particles float about the air in which we live and breathe and are stirred up by vacuuming, dusting and even walking. Common particle pollutants include lint, dust, smoke and fibers.

B Gases

Gaseous air pollutants like carbon monoxide can be especially dangerous. Typically, this type of contamination occurs from the process of combustion. Exposure to these combustible gases can cause respiratory distress, long-term lung damage and, in some cases, death. Pollutants sources that produce carbon monoxide include cooking stoves and other heat sources that use gasoline, kerosene, oil, wood or charcoal. Other types of gaseous pollutants include fumes from paint, adhesive, cleaning products and pesticides (Lipsett, 1992).

C Biological

Biological contamination comes from most anything that is derived from living tissue. Common types of biological pollutants are mold, dust mites, bacteria, pollen, pet dander, cat saliva and cockroaches. Other things that have the potential to become dangerous biological pollutants are dried urine from pests and rodents, human colds or

viruses and central air-conditioning systems that can breed mold and mildew. These latter types of biological contaminants can easily become airborne and spread throughout an entire building (Mudarri, 2007).

D Radon

Radon is another potentially lethal type of indoor air pollutant. Radon, which is a naturally occurring element formed by the disintegration of radium, enters homes and other buildings in a variety of ways such as through floor drains, other kinds of drains and cracks in walls or foundations. According to the American Lung Association, radon exposure is the second leading cause of lung cancer and may be responsible for thousands of deaths from lung cancer in the United States each year (Lipsett, 1992).

2.3.2 Causes of Indoor Air Pollution

The following are some of the causes of indoor air pollution along with how they originate and generated to appear in the forms pr categories identified above:

i. Radon: often found in the bedrock underneath a home and in building material

ii. Environmental tobacco smoke: the combination of smoke coming from the burning end of a cigarette, pipe or cigar, as well as the smoke exhaled by the smoker. (David, 2010).

iii. Biological contaminants: bacteria, mold, mildew, viruses, animal dander, dust mites, cockroaches and pollen. Many of these grow in damp, warm environments or are brought in from outside.

iv. Combustion: unvented gas space heaters, woodstoves, fireplaces and gas stoves emit carbon monoxide, nitrogen dioxide and small particles. More than 3 billion

people worldwide continue to rely on solid fuels like wood and coal for their energy needs (World Health Organization).

v. Household products: paints, varnishes, hobby products and cleaning products all contain organic chemicals that are released during use and storage

vi. Pesticides: 80 percent of most people's exposure to pesticides happens inside; measurable levels of up to 12 pesticides have been detected in indoor air (source: EPA).

The potential for harm from any of these pollutants depends partly on our individual sensitivity. The elderly, the young and those with compromised immune systems tend to be more susceptible. Ventilation also plays a role in how these pollutants harm you. If fresh air frequently circulates throughout the area, the culprits won't have as much time to accumulate and reach dangerous levels. Going back to the bathtub analogy, ventilation is like slowly draining out the oily bathtub water and adding clean water in its place: Eventually, the oil will become less and less of a problem. But if you keep the plug in and do nothing, you're going to have one nasty bathtub ring. Unfortunately, many newer, energy-efficient buildings are practically airtight they're like the plugged-up bathtub.

2.4 HEALTH PROBLEM CAUSED BY COMBUSTION PRODUCTS (STOVES, SPACE HEATERS, FURNACES, FIREPLACES AND BURSEN BURNERS)

The following are some of the key symptoms that indicates that the indoor air quality has being affected by combustion activity either within the interior or from the activities outside the interior: (Olopade, 2009)

i. dizziness or headache
ii. confusion
iii. nausea/emesis
iv. fatigue
v. tachycardia
vi. eye and upper respiratory tract irritation
vii. wheezing/bronchial constriction
viii. persistent cough
ix. elevated blood carboxyhemoglobin levels
x. increased frequency of angina in persons with coronary heart disease

2.4.1 Diagnostic Leads of the Impact of Combustion on the Indoor Air Quality

i. What types of combustion equipment are present, including gas furnaces or water heaters, stoves, unvented gas or kerosene space heaters, clothes dryers, fireplaces? Are vented appliances properly vented to the outside?
ii. Are household members exhibiting influenza-like symptoms during the heating season? Are they complaining of nausea, watery eyes, coughing, headaches?
iii. Is a gas oven or range used as a home heating source?

iv. Is the individual aware of odor when a heat source is in use?

v. Is heating equipment in disrepair or misused? When was it last professionally inspected?

vi. Does structure have an attached or underground garage where motor vehicles may idle?

vii. Is charcoal being burned indoors in a hibachi, grill, or fireplace?

2.5 BY-PRODUCTS OF COMBUSTION ACTIVITIES AND THEIR HELTH IMPACT ON THE INDOOR AIR QUALITY

Aside from environmental tobacco smoke, the major combustion pollutants that may be present at harmful levels in the home or workplace stem chiefly from malfunctioning heating devices, or inappropriate, inefficient use of such devices. Incidents are largely seasonal. Another source may be motor vehicle emissions due, for example, to proximity to a garage (or a loading dock located near air intake vents).A variety of particulates, acting as additional irritants or, in some cases, carcinogens, may also be released in the course of combustion. Although faulty venting in office buildings and other nonresidential structures has resulted in combustion product problems, most cases involve the home or non-work-related consumer activity. Among possible sources of contaminants: gas ranges that are malfunctioning or used as heat sources; improperly fluid or vented fireplaces, furnaces, wood or coal stoves, gas water heaters and gas clothes dryers; and unvented or otherwise improperly used kerosene or gas space heaters. (HUD 2005)

The gaseous pollutants from combustion sources include some identified as prominent atmospheric pollutants ; carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) (Rogge et al, 1993).

2.5.1 Carbon Monoxide (CO)

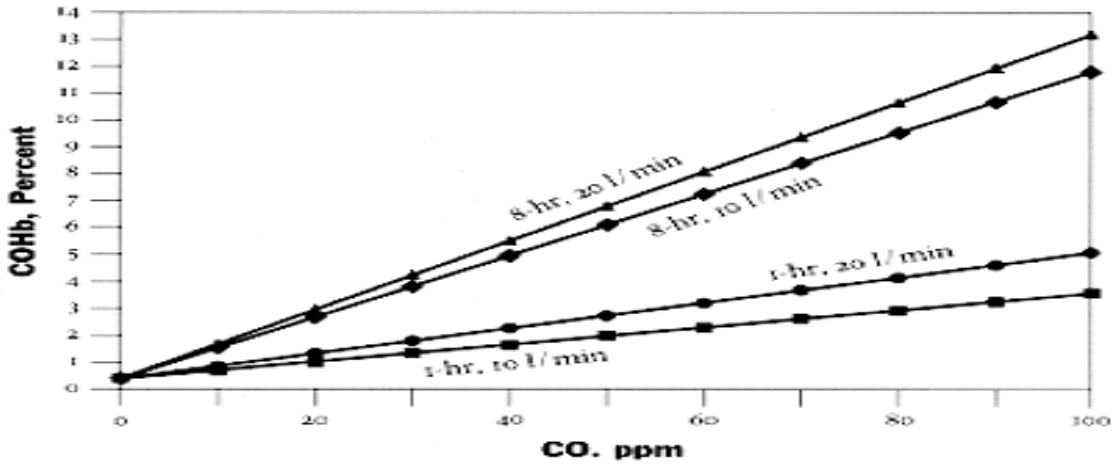
Carbon-monoxide is an asphyxiant. Carbon monoxide is an odorless, colorless gas that can cause illness, loss of consciousness, and even death. The most common symptoms of CO poisoning are headache, dizziness, weakness, nausea, vomiting, chest pain, and confusion. Unless suspected, CO poisoning can be difficult to diagnose because the symptoms mimic other illnesses. People who are sleeping or intoxicated can die from CO poisoning before ever experiencing symptoms. The toxic effects of carbon monoxide are usually associated with acute exposure. However, low-level exposure to carbon monoxide may produce long-term effects without producing the typical symptoms associated with acute exposure (HUD 2005).

An accumulation of this odorless, colorless gas may result in a varied constellation of symptoms deriving from the compound's affinity for and combination with hemoglobin, forming carboxyhemoglobin (COHb) and disrupting oxygen transport. The elderly, the fetus, and persons with cardiovascular and pulmonary diseases are particularly sensitive to elevated CO levels. Methylene chloride, found in some common household products, such as paint strippers, can be metabolized to form carbon monoxide which combines with hemoglobin to form COHb. The following chart shows the relationship between CO concentrations and COHb levels in blood.

Tissues with the highest oxygen needs -- myocardium, brain, and exercising muscle are the first affected. Symptoms may mimic influenza and include fatigue, headache,

dizziness, nausea and vomiting, cognitive impairment, and tachycardia. Retinal hemorrhage on funduscopic examination is an important diagnostic sign, but COHb must be present before this finding can be made, and the diagnosis is not exclusive. Studies involving controlled exposure have also shown that CO exposure shortens time to the onset of angina in exercising individuals with ischemic heart disease and decreases exercise tolerance in those with chronic obstructive pulmonary disease (COPD) (Gergan,1992).

Note: Since CO poisoning can mimic influenza, the health care provider should be suspicious when an entire family exhibits such symptoms at the start of the heating season and symptoms persist with medical treatment and time.



Source: U.S. EPA ,1985
Fig 2.1: Relationship between carbon monoxide (CO) concentrations and carboxyhemoglobin (COHb) levels in blood

Predicted COHb levels resulting from 1- and 8-hour exposures to carbon monoxide at rest (10 l/min) and with light exercise (20 l/min) are based on the Coburn-Foster-Kane equation using the following assumed parameters for nonsmoking adults: altitude = 0 ft; initial COHb level = 0.5%; Haldane constant = 218; blood volume = 5.5 l; hemoglobin

level = 15 g/100ml; lung diffusivity = 30 ml/torr/min; endogenous rate = 0.007 ml/min. Fig 2.1 gives the COHb level at various percentage with varying degree of exposure, from the figure above four range of exposure have being indentified, however table 2.1 butresss the explanation by specifying the consequent health implication at various percentage of COHB level in the body.

Table 2.1: Carboxyhemoglobin levels and related health effects

% COHb in blood	Effects Assocated with this COHb Level
80	Death
60	Loss of consciousness; death if exposure continues
40	Confusion; collapse on exercise
30	Headache; fatigue; impaired judgmental
7-20	Statistically significant decreased maximal oxygen consumption during strenuous exercise in healthy young men
5-17	Statistically significant diminution of visual perception, manual dexterity, ability to learn, or performance in complex sensor motor tasks (such as driving)
5-5.5	Statistically significant decreased maximal oxygen consumption and exercise time during strenuous exercise in young healthy men
Below 5	No statistically significant vigilance decrements after exposure to CO
2.9-4.5	Statistically significant decreased exercise capacity (i.e., shortened duration of exercise before onset of pain) in patients with angina pectoris and increased duration of angina attacks
2.3-4.3	Statistically significant decreased (about 3-7%) work time to exhaustion in exercising healthy men

Source**:** U.S. EPA, 1985

2.5.2 Nitrogen dioxide (NO)

Nitrogen dioxide act mainly as irritants, affecting the mucosa of the eyes, nose, throat, and respiratory tract.. Extremely high-dose exposure (as in a building fire) to NO_2 may result in pulmonary edema and diffuse lung injury. Continued exposure to high NO_2 levels can contribute to the development of acute or chronic bronchitis (Gold, 1992).

The relatively low water solubility of NO_2 results in minimal mucous membrane irritation of the upper airway. The principal site of toxicity is the lower respiratory tract. Recent studies indicate that low-level NO_2 exposure may cause increased bronchial reactivity in some asthmatics, decreased lung function in patients with chronic obstructive pulmonary disease, and an increased risk of respiratory infections, especially in young people.

NO_2 is a potential cause of respiratory disease. The NAAQS set by the U.S. EPA enacted a primary outdoor standard for NO_2 of 100 parts per billion (ppb) for a 1-hour average (EPA 2010). It should be noted that the (National Ambient Air Quality Standard, 2011) is not intended for application to indoor air but is used as a comparative reference level. The WHO guideline is 110 ppb for a 1-hour average, which applies to both indoor and outdoor air (WHO 2000). Health Canada has residential indoor air quality guidelines for a 24-hour average (50 ppb) and for a 1-hour average (250 ppb) (Health Canada 2011).

2.5.3 Sulphur oxides (SO, SO2)

Sulphur oxides are mainly generated during the combustion of fossil fuels. As far as wood, (containing hardly any sulphur) is concerned; sulphur oxides do not play an important part. Their occurrence is more important during the combustion of dung.

Sulphur, as a component of fuels, occurs primarily in coal, petrol, kerosine and diesel. SO_2 serves among more than 1000 air pollutants as the most important indicator for air pollution. The existence of sulphur oxide in the air leads to irritations of the mucous membranes and of the eyes, as well as to chronic bronchitis. Acute SO_2-related bronchial constriction may also occur in people with asthma or as a hypersensitivity reaction. The high water solubility of SO_2 causes it to be extremely irritating to the eyes and upper respiratory tract, Concentrations above six parts per million produce mucous membrane irritation. Epidemiologic studies indicate that chronic exposure to SO_2 is associated with increased respiratory symptoms and decrements in pulmonary function. Clinical studies have found that some asthmatics respond with broncho constriction to even brief exposure to $S0_2$ levels as low as 0.4 parts per million (Gold, 1992).

2.5.4 Formaldehyde

Formaldehyde has been classified as a probable human carcinogen by the EPA. Urea-formaldehyde foam insulation (UFFI), one source of formaldehyde used in home construction until the early 1980s, is now seldom installed, but formaldehyde-based resins are components of finishes, plywood, paneling, fiberboard, and particleboard, all widely employed in mobile and conventional home construction as building materials (subflooring, paneling) and as components of furniture and cabinets, permanent press fabric, draperies, and mattress ticking.

Airborne formaldehyde acts as an irritant to the conjunctiva and upper and lower respiratory tract. Symptoms are temporary and, depend upon the level and length of exposure may range from burning or tingling sensations in eyes, nose, and throat to chest tightness and wheezing. Acute, severe reactions to formaldehyde vapor -- which has a

distinctive, pungent odor -- may be associated with hypersensitivity. It is estimated that 10 to 20 percent of the U.S. population, including asthmatics, may have hyperreactive airways which may make them more susceptible to formaldehyde's effects

2.5.5 Particulate Substances

Many of the particles produced by unvented combustion appliances are ultrafine particles (i.e., particle diameters of less than 100 nm). Ruiz et al. (2010) measured higher ultrafine particle concentrations in homes with unvented combustion compared to those with electric heaters.

Ultrafine particles have recently been linked to health effects such as oxidative damage to DNA and mortality (Stölzel 2008; Knol et al. 2009; Vinzents et al. 2005). There are currently no standards or guidelines on ultrafine particles.

2.6 SOME COMMON DISEASES RESULTING FROM POOR INDOOR AIR QUALITY CONDITION

2.6.1 Tuberculosis

The transmission of airborne infectious diseases is increased where there is poor indoor air quality. The rising incidence of tuberculosis is at least in part a problem associated with crowding and inadequate ventilation. Evidence is increasing that inadequate or inappropriately designed ventilation systems in health care settings or other crowded conditions with high-risk populations can increase the risk of exposure (American Lung Association, 1992).

The incidence of tuberculosis began to rise in the mid 1980s, after a steady decline. The 1989 increase of 4.7 percent to a total of 23,495 cases in the United States

was the largest since national reporting of the disease began in 1953, and the number of cases has continued to increase each year. Fresh air ventilation is an important factor in contagion control. Such procedures as sputum induction and collection, bronchoscopy, and aerosolized pentamidine treatments in persons who may be at risk for tuberculosis (e.g., AIDS patients) should be carried out in negative air pressure areas, with air exhausted directly to the outside and away from intake sources. Unfortunately, many health care facilities are not so equipped. Properly installed and maintained ultraviolet irradiation, particularly of upper air levels in an indoor area, is also a useful means of disinfection (Zhang, 2005).

2.6.2 Legionnaires' Disease

A disease associated with indoor air contamination is Legionnaires 'disease, a pneumonia that primarily attacks exposed people over 50 years old, especially those who are immunosuppressed, smoke, or abuse alcohol. Exposure to especially virulent strains can also cause the disease in other susceptible populations. The case fatality rate is high, ranging from five to 25 percent. Erythromycin is the most effective treatment. The agent, *Legionella pneumophila*, has been found in association with cooling systems, whirlpool baths, humidifiers, food market vegetable misters, and other sources, including residential tap water. This bacterium or a closely related strain also causes a self-limited (two- to five-day), flu-like illness without pneumonia, sometimes called Pontiac Fever, after a 1968 outbreak in that Michigan city (American Lung Association, 1990).

2.6.3 Allergic Reactions

A major concern associated with exposure to biological pollutants is allergic reactions, which range from rhinitis, nasal congestion, conjunctival inflammation, and urticaria to asthma. Notable triggers for these diseases are allergens derived from house dust mites; other arthropods, including cockroaches; pets (cats, dogs, birds, rodents); molds; and protein-containing furnishings, including feathers, kapok, etc. In occupational settings, more unusual allergens (e.g., bacterial enzymes, algae) have caused asthma epidemics. Probably most proteins of non-human origin can cause asthma in a subset of any appropriately exposed population. (Zhang, 2005)

The role of mites as a source of house dust allergens has been known for 20 year. It is now possible to measure mite allergens in the environment and Age antibody levels in patients using readily available techniques and standardized protocols. Experts have proposed provisional standards for levels of mite allergens in dust that lead to sensitization and symptoms. A risk level where chronic exposure may cause sensitization is 2µg Der pI (*Dermatophagoides pteronysinus* allergen I) per gram of dust (or 100 mites /g or 0.6 mg guanine /g of dust). A risk level for acute asthma in mite-allergic individuals is 10µg (Der pI) of the allergen per gram of dust (or 500 mites /g of dust).

2.6.4 Hypersensitivity Pneumonitis

Another class of hypersensitivity disease is hypersensitivity pneumonitis, which may include humidifier fever. Hypersensitivity pneumonitis, also called allergic alveo-litis, is a granulomatous interstitial lung disease caused by exposure to airborne antigens. It may affect from one to five percent or more of a specialized population exposed to appropriate antigens (e.g., farmers and farmers' lung, pigeon breeders and pigeon

breeders' disease). Continued antigen exposure may lead to end-stage pulmonary fibrosis. Hypersensitivity pneumonitis is frequently misdiagnosed as pneumonia of infectious etiology. The prevalence of hypersensitivity pneumonitis in the general population is unknown (Gergan, 1992).

Outbreaks of hypersensitivity pneumonitis in office buildings have been traced to air conditioning and humidification systems contaminated with bacteria and molds. In the home, hypersensitivity pneumonitis is often caused by contaminated humidifiers or by pigeon or pet bird antigens. The period of sensitization before a reaction occurs may be as long as months or even years. An acute symptom, which occurs four to six hours post exposure and recur on challenge with the offending agent, include cough, dyspnea, chills, myalgia, fatigue, and high fever. Nodules and nonspecific infiltrates may be noted on chest films. The white blood cell count is elevated, as is specific to the offending antigen. Hypersensitivity pneumonitis generally responds to corticosteroids or cessation of exposure (either keeping symptomatic people out of contaminated environments or removing the offering agents. (Zhang, 2005)

2.6.5 Humidifier Fever

Humidifier fever is a disease of uncertain etiology. It shares symptoms with hypersensitivity pneumonitis, but the high attack rate and short-term effects may indicate that toxins (e.g., bacterial endotoxins) are involved. Onset occurs a few hours after exposure. It is a flu-like illness marked by fever, headache, chills, myalgia, and malaise but without prominent pulmonary symptoms. It normally subsides within 24 hours without residual effects, and a physician is rarely consulted. Humidifier fever has been related to exposure to amoebae, bacteria, and fungi found in humidifier reservoirs, air

conditioners, and aquaria. The attack rate within a workplace may be quite high, sometimes exceeding 25 percent. (American Thoracic Society, 1990)

Bacterial and fungal organisms can be emitted from impeller (cool mist) and ultrasonic humidifiers. Mesophilic fungi, thermophilic bacteria, and thermophilic actinomycetes -- all of which are associated with development of allergic responses have been isolated from humidifiers built into the forced-air heating system as well as separate console units. Airborne concentrations of microorganisms are noted during operation and might be quite high for individuals using ultrasonic or cool mist units. Drying and chemical disinfection with bleach or 3% hydrogen peroxide solution are effective remedial measures over a short period, but cannot be considered as reliable maintenance. Only rigorous, daily, and end-of-season cleaning regimens, coupled with disinfection, have been shown to be effective. Manual cleaning of contaminated reservoirs can cause exposure to allergens and pathogens (Hine et'al, 1993).

2.7 CONCEPT OF UNVENTED COMBUSTION AND ITS HEALTH IMPACT

Unvented combustion heaters use indoor air for combustion and vent the combustion by-products directly into the room. They usually burn kerosene or natural gas. Kerosene burning heaters are typically portable and can be moved around where and when needed. When operated and maintained properly, these systems can be up to 98% efficient, and introduce little indoor air pollution to the room. However, most building scientists and indoor air quality professionals do not recommended ventless heaters in homes where moisture problems exist, or where small people and elderly persons live or where the heater is likely to be operated for more than 2 hours per day. Under NO

circumstances should you ever install vent less heaters in airtight houses, mobile homes, or trailers (ANSI Z223.1-2006/NFPA 54-2009).

Occupant safety is a major concern when operating an unvented combustion heater. Poorly made, maintained, or operated units have caused fires and other combustion-related accidents. Improperly installed or malfunctioning vent less heaters often introduce carbon monoxide (CO), nitrous oxides (NOx), sulfur dioxide (SO2), and large amounts of water vapor, and possible consume most of the oxygen in a room. Depending upon the level of exposure, these pollutants and the lack of oxygen can cause eye irritation, headaches, dizziness, fatigue, respiratory problems, and possibly death (MMWR, 1997).

Unvented combustion equipment may be found in almost any occupancy classification, although some are more common than others. Unvented heaters are permitted to be installed in most jurisdictions, but prohibitions or restrictions exist in some locations. All state codes permit the installation of unvented cooking appliances (ASHRAE, 2012).

The National Fuel Gas Code, ANSI Z223.1/NFPA 54 published jointly by the National Fire Protection Association (NFPA) and the American Gas Association (AGA), governs the installation of unvented gas-fired room heaters, but prohibits installation in certain occupancies, which include residential board and care or health care (ANSI Z223.1/NFPA 54-2009). The International Fuel Gas Code, published by the International Code Council (ICC), also governs the installation of unvented gas-fired room heaters but prohibits installation in assembly, educational, and institutional occupancies (ICC 2012). NFPA 501, Standard on Manufactured Housing prohibits the installation of unvented

room heaters in manufactured housing as part of the construction code (NFPA 501-2010). Once the manufactured home is sited, unvented gas-fired room heaters can be installed where allowed by state and local code.

The Life Safety Code (NFPA 101-2012), allows gas-fired room heaters that are in compliance with ANSI Z223.1/NFPA 54 but prohibits the use of unvented fuel-fired heating equipment, including kerosene and denatured alcohol, from being used in educational, day care, rooming/ lodging, hotel/dormitory, apartment, and health care occupancies. Portable space heating devices are prohibited in detention/correctional facilities.

Unvented combustion heaters, including propane and natural gas-fired heaters listed to the *Standard for Gas-Fired Room Heaters,Vol. II, Unvented Room Heaters* (ANSI Z21.11.2-2007), and kerosene heaters listed to the *Standard for Unvented Kerosene-Fired Room Heaters and Portable Heaters* (UL 647-1993), are most commonly found in residential occupancies.

Gas-fired room heaters, especially gas log types, are sometimes used in hotel/lodging common areas and assembly occupancies, such as restaurants, for their aesthetic effect ASHRAE (2012).)

In commercial building and storage occupancies the use of unvented combustion room heaters is very rare, although not prohibited by NFPA 101 or the International Fuel Gas Code (IFGC). Unvented infrared radiant heaters can be found in industrial occupancies, such as aircraft hangers, repair garages, or similar large open spaces requiring localized heating for the workers.

The Third National Health and Nutrition Examination Survey (NHANES III) estimated that 13.7 million adults have at some time used an unvented combustion space heater. Since 1992, use of unvented combustion heaters has increased because in many states, regulations prohibiting the use of these devices have been rescinded (MMWR 1997).

About 170 people in the United States die every year from carbon monoxide (CO) produced by non-automotive consumer products. These products include malfunctioning fuel-burning appliances such as furnaces, gas ranges, water heaters, room heaters, engine-powered equipment such as portable generators, solid-fuel burning fireplaces, and charcoal that is burned in homes and other enclosed areas (CPSC 2011b). Since 1984 the U.S. Consumer Product

Safety Commission (CPSC) staff has collected data on fatal CO poisonings and is not aware of any documented incident associated with a gas-fired space heater complying with ANSI Z21.11.2-1982, though such an incident was not precluded (Switzer 2005).

The installation and usage of these appliances have an impact on indoor air quality. When improperly installed or maintained or misused the potential for harmful emissions being released into the living space increases (ASHRAE, 2012).

2.8 UNVENTED COMBUSTION EQUIPMENT

The following are some of the unvented combustion equipment and the provision of use by the ASHRAE Position Document on Unvented Combustion Devices and Indoor Air Quality (2012)

2.8.1 Natural and Propane Gas-Fired Unvented Room and Hearth Heaters

Unvented gas-fired room heaters are designed for permanent installation to a gas piping system and securely mounted in a fixed position. Various designs include room heaters (e.g., infrared and blue-flame) and hearth heaters (e.g., gas logs and fireplaces). These appliances can have single or multiple heating capacities. They can be either thermostatically or manually controlled.

In the United States, the industry consensus product safety standard covering unvented gas-fired unvented room heaters and hearth (fireplace) products is the American National Standard for *Gas-Fired Room Heaters, Volume II, Unvented Room Heaters*, ANSI Z21.11.2. Installation codes, such as the National Fuel Gas Code, require gas-fired unvented space heaters to be listed to the Z21.11.2 standard. The Z21.11.2 standard applies to newly produced room heaters for permanent connection to the building fuel supply system. The scope of the standard limits the size and gas input rate to 40,000 Btu/h (11723 W), except for bedroom and bathroom installations, where the input rate limitation is reduced to 10,000 and 6,000 Btu/h (2931W and 1758 W), respectively.

The Z21.11.2 standard requires these appliances to be equipped with a number of safety devices including an oxygen depletion safety shutoff device (ODS) that is designed to shut off the gas supply to the main burner when the oxygen level in the surrounding atmosphere is reduced to not less than 18%. In addition, each certified heater design is tested and evaluated for combustion and burner operating characteristics. Laboratory combustion testing limits the emissions of CO to 0.02% air-free, and NO2 to 0.002% air-free. In addition, a heater cannot produce CO in excess of 0.025% in a room with no air

changes occurring during combustion of the amount of gas necessary to reduce the oxygen content of the room to 15.1% by volume.

2.8.2 Natural and Propane Gas-Fired Cooking Appliances

Gas-fired residential cooking equipment is inherently unvented. In some cases, range hoods which are vented to the outside will partially serve the venting function, but range hoods are installed primarily to vent emissions from the cooking process, e.g., smoke, grease, steam, and odors. For this reason, where they are required by code, they are required for both electric and fuel-fired appliances. It should also be noted that many range hoods do not vent to the outdoors, but are recirculating hoods which are primarily intended to remove grease and other large particles from the airstream.

In the United States, the industry consensus product safety standard covering gas-fired cooking appliances is the American National Standard for *Household Cooking Gas Appliances*,

ANSI Z21.1-2010. National, state, and local codes, such as the National Fuel Gas Code and the U.S. Manufactured Home Construction and Safety Standard, govern the proper installation of these appliances.

ANSI Z21.1 standard requires that an appliance shall not produce a concentration of CO in excess of 0.08 percent in an air-free sample of the flue gases when the appliance is tested in a room having approximately a normal oxygen supply. ASHRAE Standard 62.2 (ASHRAE 2010) includes a requirement for local exhaust in the kitchen, which should be operated whenever cooking appliances are used to assist in the removal of smoke and effluents produced by the cooking process.

2.8.3 Natural and Propane Gas-Fired Unvented Heaters

A study by Francisco et al. (2010) measured indoor air concentrations in 30 homes that used unvented gas heaters manufactured since 1980. This study found that 20% of homes exceeded the EPA and WHO threshold for an 8-hour average CO level of 9 ppm, primarily when they were used for continuous, extended periods of time. This usage pattern is contrary to industry recommendations, which state that unvented heaters should be used as supplemental heaters, not primary heaters or for excessive periods of time. The study also showed that 80% of units produced NO2 levels greater than the WHO 1-hour levels. The same number of units also exceeded the EPA outdoor standard 1-hour reference level, though the sampling time of 3–4 days is less than the method of test duration of 3 years required by the EPA standard. The EPA standard was not intended for indoor spaces. ANSI Z21.11.2, which requires that appliances comply with a maximum NO_2 level, was based on a 300 ppb level that had been recommended by the Consumer Products Safety Commission at the time. Francisco et al. found that 60% of homes met the 300 ppb for a 1-hour average. (It should be noted that the 300 ppb standard went into effects after most units in the study had been manufactured.)

Francisco et al. also found that regardless of unvented fireplace usage pattern, the relative humidity rarely exceeded 50% in 30 homes tested in Central Illinois. Francisco et al. commented that winter humidity levels in Central Illinois are low. Whitmyre and Pandian (2004) used modeling to show that, given assumptions about usage and house characteristics, unvented heating appliances did not produce enough moisture to result in indoor relative humidity levels that promote mold growth in United States DOE Climate Zones 2–5, and only in about 5% of cases in Climate Zone 1.

The potential for moisture concerns in a laboratory is complex. It depends on sources, local ventilation, and temperature conditions at surfaces, etc. It also depends on the time of year and the moisture- generating processes undertaken at those times of year. Gas-fired cooking appliances may be used throughout the year, regardless of background humidity levels. Gas-fired heating equipment will be used primarily in the winter, when conditions are dry in many but not all locations.

All of these factors must be taken into account when assessing the potential for any source, including unvented combustion, to promote moisture conditions of concern. Hedrick and Krug (1995) measured emissions from unvented gas-fired space heaters that used different heat transfer technologies. The different device types are intended to reduce emission rates of one pollutants or another. A blue-flame heater allows the combustion process to continue to its natural completion. This results in low CO emissions but the combustion process's extended time at high temperature increases NO and NO_2 emissions. A radiant tile heater and a perforated tube heater both impinge the flame onto surfaces, quenching the combustion. The quenching terminates the production of NO_2, but it also terminates the formation of CO_2, resulting in increased CO emissions relative to the blue-flame heater. A fan-forced heater requires an electrical connection, which the others do not, but the fan allows the designers to better control the combustion and reduce emissions. This unit had low emissions of all contaminants, but the unit tested was only available in Japan, where use of unvented heaters is common.

2.9 VENTILATION CONSIDERATIONS

In addition to fuel, the operation of any combustion system requires the provision of oxygen and the removal of products of combustion. At a basic level, these processes

are required simply to allow combustion to occur. For an unvented combustion appliance, the provision of oxygen occurs by drawing in room air to the combustion zone, and the products of combustion are dispersed into the room. Over time, without providing adequate make-up, combustion, and ventilation air, the oxygen in the room is consumed and the concentration drops, while products of combustion accumulate with concentrations increasing. The result is decreasing indoor air quality (Bergmann, 2006).

Ventilation of the room is one means by which this decrease in indoor air quality can be controlled. Ventilation of the room provides outdoor air, including oxygen, to replace the oxygen that is consumed. Additionally, ventilation removes air from the space, including the products of combustion. The indoor air quality in a space containing an unvented combustion appliance is thus determined by two primary factors: pollutants emission rates and the ventilation rate. Emission rates are the time-averaged amount of fuel combustion (fuel input rate × fractional on-time) multiplied by the individual emission factors for the specific contaminants. Volume of the space is a secondary factor which affects the indoor air quality level for dynamic (non-steady state) processes, which includes most real world applications of the factors that affect indoor air quality, in general, only two are under the control of the user. The on-time of the appliance is controlled by the user, either directly or through the setting of a thermostatic control. The ventilation rate is also controllable, in some circumstances and to some extent, by the user. This control might be through window opening, or through ensuring that a primary ventilation system is operating. Excessive appliance operation will increase the amount of contaminants in the space, degrading the air quality. Provision of adequate ventilation

will provide air for proper combustion, remove contaminants, and improve air quality (Bergmann, 2006).

A key component of high quality installation is ensuring that a space has adequate ventilation and make-up air. If the provision of adequate ventilation is dependent on the operation of fans, windows, or doors, etc., then it is critical that the user has access to these and understands their proper use. Failure to provide adequate ventilation can result in elevated contaminant concentrations and increase the risk of poor indoor air quality, health impacts, water condensation, and other adverse consequences.

ASHRAE standard 62-1989 describes the Ventilation recommendations as 15 - 20 CFM (cubic feet per *minute*) *per person* in *offices or classrooms*. I.e.) 20 people in a 750 sq. ft. classroom with 10 ft. ceilings = Room is 7,500 cubic feet 20 people x 15 CFM = 300 CFM/ room or 300 x 60 for (1hr) = 18,000 CF/H – 18,000 / 7,500 = 2.4 air exchanges per hour

(This is the minimum required) 7,500 cubic feet / 300 CFM = 25 people max can occupy the room

The recommendations for *bus garages* are 1.5 CFM *per square foot of floor area.* This means that a 2,100 square foot of floor area should have an air system capable of moving air at a rate of 3,150 CFM. (2,100 x 1.5) ASHRAE also notes that in a bus garage, distribution among people must consider worker location and concentration of running engines and that stands where engines are run must incorporate systems for positive engine exhaust withdrawal.

2.10 ASHRAE PROVISION FOR THE DESIGN OF THE HVAC SYSTEM OF A LABORATORY

Heating, Ventilation, and Air-Conditioning Systems for Research Laboratories and Animal Facilities: Heating, ventilation, and air-conditioning (HVAC) systems for Research Laboratories shall be designed to maintain the space temperature and humidity at the required set point. These systems shall automatically adjust, as necessary, to respond to varying space cooling demands in laboratories and animal facilities. Air-change rates, temperature and humidity shall be closely monitored and controlled on a continuous basis. The System shall provide adequate ventilation to remove fumes, odors, airborne contaminants, and to safely operate fume hoods continuously. They shall be designed to maintain relative pressure differentials between spaces to prevent of cross contamination. Space background noise, generated by HVAC systems, shall be maintained within the levels prescribed within this document. HVAC systems shall be reliable, redundant and operate without interruption while being efficient to operate, both in terms of energy consumption and from a maintenance perspective.

2.10.1 Laboratory Ventilation Rates:

Ventilation rate, for research laboratories, is typically driven by three factors: fume hood demand, cooling loads, and removal of fumes and odors from the laboratory work area. The minimum outdoor air ventilation rate for laboratory space is 6 air-changes per hour, regardless of space cooling load. This minimum ventilation rate shall be maintained at all times. Some laboratories may require significantly higher ventilation rates to support fume hood demand or to cool dissipated heat from laboratory instruments and equipment.

Air Filtration – Air handling units to serve laboratory spaces shall be provided with filters up-stream the supply air fans. These filters shall be 30% efficient pre-filters and 95% efficient after-filters. HEPA final filtration shall be provided in AHU to serve special laboratories where research materials are particularly susceptible to contamination from external sources. HEPA filtration of the supply air shall only be considered necessary for critical applications. It is preferred that BSCs, which include HEPA filtration, be used rather than providing HEPA filtration for the entire room. The A/E shall confirm with NIH/DTR and NIH/DOHS for the need of HEPA filtration in laboratories.

a) **Air Distribution**:

Laboratory spaces shall be designed with special attention to air quality, room acoustics, supply air temperature, supply air humidity, airflow quantities, air velocity, and air diffusion and distribution within the space. In addition, space air distribution shall meet the following requirements:

i) Distribution shall prevent cross contamination between individual spaces, air shall flow from areas of least contamination to areas of higher contamination potential, i.e., from "clean" to "dirty" areas.

ii) Air supply devices shall be located at ceiling level or close to ceiling level if located on sidewalls. Air distribution and diffusion devices shall be selected to minimize temperature gradients and air turbulence.

iii) Supply air devices shall be located away from fume hoods and BSC.

iv) Large quantities of supply air can best be delivered through perforated plate air

outlets or diffusers designed for large air volumes.

v) Space temperature and humidity shall be consistent in each individual room. Space temperature shall be monitored in each individual room

vi) Each lab space shall be provided with dedicated temperature controls. This shall include the used of dedicated air-terminal units for the supply air and the exhaust air.

b) Relative Room Pressurization:

Laboratories shall be designed and air balanced so that air flows into the laboratory from adjacent (clean) spaces such as: offices, corridors, and non-laboratory spaces. The control of airflow direction, within research laboratory spaces, helps reduce the spread of odors, toxic chemicals, and air-borne contaminants as well as protect personnel from toxic and hazardous substances, and protect the integrity of experiments. In these facilities, the use of the once-through air-flow principle is based on:

i. Use of 100% outdoor air to provide all the room air to be exhausted through laboratory spaces and laboratory containment equipment;

ii. Size the exhaust air system to handle the simultaneous operation of all laboratory spaces and all laboratory containment equipment, and

iii. Directing air flow from low hazard areas to high hazard areas at all times. Air supplied to the corridor and adjacent clean spaces shall be exhausted through the laboratory to achieve effective negative pressurization. Construction Documents shall include a complete start-up and commissioning plan including procedures

that address indoor air quality requirements.

Laboratory spaces shall remain at a negative air pressure in relation to corridors and other non-laboratory spaces. Typically, these systems are designed to maintain 47 L/s (100 cfm) air flow from the corridor into each lab module. Administration areas in laboratory buildings shall always be positive with respect to corridors and laboratories. Supply air distribution for corridors shall be sized to offset transfer air to laboratories while maintaining an overall positive building pressure.

Amount of supply air flow to laboratory spaces is to meet the cooling loads requirements as well as the exhaust air requirements. Typically, the exhaust airflow requirements would exceed the cooling loads requirements. In these situations, the supply air flow would need to be increased to make up the difference between the cooling air flow and the required exhaust air flow. In cases where the cooling load airflow requirements exceed the required exhaust air rate requirements, supplemental cooling units may be required.

c) Laboratory Equipment Cooling Loads:

The central HVAC system shall provide, as a minimum, a cooling capacity for 1,892 W (6,455 BTUH) (sensible heat) for laboratory equipment in a typical 22 m2 (237 ft2) laboratory module or cooling for the actual calculated load, whichever is greater. The A/E shall make a detailed and complete inventory of all laboratory equipment scheduled for installation in each space and determine the projected equipment load requirement using estimated utilization factors. Equipment utilization factors shall be indicated in the Basis of Design report. The A/E shall evaluate the following rooms used

for laboratory support, often having higher than normal cooling loads, as well as evaluate the use of supplemental cooling units to remove excessive sensible loads affecting these areas, while maintaining minimum ventilation requirements:

i. Common equipment rooms.

ii. Autoclave rooms.

iii. "Clean" and "dirty" cage wash rooms.

iv. Glassware washing rooms.

v. Darkrooms.

vi. Special function rooms.

vii. Electron microscope.

2.11 HVAC SYSTEMS AS A TOOL IN CONTROLLING INDOOR AIR QUALITY

The impact of Heating Ventilation and Air Conditioning system on the indoor air quality has being a controversial issue; however several researches have being conducted in this aspect, example of such research include. Samfield(1996), reviewed several literatures on the impact of HVAC system as a tool in controlling Indoor Air quality. The study review covered 60 references within these years 1988 through 1993. The result of the review shows that although significant progress has been made in reducing the energy consumption of HVAC systems, the role of HVAC systems in affecting indoor air

pollution is not fully understood. It is apparent that the HVAC systems themselves very often contribute to the indoor air pollution problem because:

a) Maintenance of the system is poor,

b) The design limitations of the building and the HVAC system have gradually, over time, been exceeded either through overcrowding or the introduction of new, pollution-generating sources within the building, and

c) The outdoor air intakes are located near ambient pollution sources. IAQ problems frequently manifest themselves through Sick Building Syndrome or Building Related Illness (SBS or BRI). These can cause a loss in employee productivity.

Samfield (1996) also recognized that failure to pay attention to IAQ problems may result in expensive litigation. The National Institute of Occupational Safety and Health (NIOSH) in a recent survey determined that in over 50% of the cases where IAQ problems existed, poor and inadequate ventilation was the problem. In cases where pollutants emanate from soil gases (e.g., radon), the installation and operation of an HVAC system can alter the IAQ. Since the entry of soil gas is, to a large extent, dependent on the pressure differential between the soil and the structure, HVAC system operation can have a significant effect. Before an HVAC system is designed and installed, all operations in the building should be thoroughly examined with regard to potential pollution sources and a determination should be made whether local exhaust systems (such as hoods) need to be installed at the pollution source. Proper installation of local exhaust systems may significantly reduce the need for general ventilation.

Two primary types of HVAC systems are in use:

a) constant air volume systems

b) Variable air volume (VAV) systems. VAV systems compensate for variations in heating or cooling load by regulating the volume of air supplied to each zone. Energy conservation as well as improved controls and equipment have made VAV an increasingly popular option.

Samfield (1996), also revealed that, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has revised Standard 62-1981, replacing it with Standard 62-1989. The revised standard now includes an updated and revised IAQ procedure for which a model has been developed, and equations for calculating the amount of recirculation needed.

2.12 INDOOR AIR POLLUTION FROM FUEL COMBUSTION

The concept of indoor air pollution has being a contemporary one, which have stirred up so many research with the general aim of emphasizing the health impact of a poor indoor air and the identification of the major pollutants of the indoor air. Some of these researches include:

Saravanan (2004), studies generally the indoor air pollution, from the result of the research, it was established that the major factors that determine the indoor air quality are:

i) The nature of outdoor air quality around the building

ii) The ventilation rate with 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 eyc)

v) The use of household chemicals

Saravana identified some of the pollutants sources as ; radio activity (the emissions from uranium in the soil or rocks on which the houses are built, Voltaic Organic Compounds(VOC) usually from aliphatic and aromatic compound, chlorinated compounds with formaldehyde being in many location. The emphasis of the sources of indoor air pollutants was on the indoor combustion activities. Combustion of fuels such as oil, gas, kerosene, etc inside a building contributes to the concentration of VOCs and it is also a source of stable inorganic gases. The common indoor pollutants due to combustion of fuels are particulate matter, oxides of nitrogen, oxides of sulphur, carbon monoxide, hydrocarbons and other odor causing chemicals. Saravana concluded by opining that Indoor air pollution is one of the major problems that we have to solve since we spend a large part of our life indoors. We should take all necessary precautions to eliminate or minimize the harmful effects of indoor air pollution.

Smith and Zhang (2005) studies the studied the indoor air pollution form household fuel combustion, the result of the finding estimated that that air pollution from solid waste in China is responsible for 420,000 premature death annually with more than 300,000 attributed to the urban outdoor. To help elucidate more fully the extent of hazard caused by combustion pollutants in China, Smith and Zhang (2005) review nearly 200 publications in china reporting health effect, emission characteristic and/or indoor concentration associated with solid fuel as well as taking measurement in 122 individual studies. Based on the measurement, Smith and Zhang were able to summarize that indoor concentration exceeding health-based standards in many of the house-holds.

In like manner Stanley (2010) assessed the environmental sustainability of electric power generators for power supply to building with view to devising appropriate control

measure for cleaner environment. The assessment was for buildings within Kaduna metropolis and the approach adopted was both with the use of a well structured questionnaire and the use of the IMR 1400C combustion gas analyzer. The result of the research showed that the level of awareness of hazard by generator was high but the level complains by neighbor was quite low. The research also revealed that the mean concentration of SO_2 and NO_x indoor were higher and even hiher than the FEPA limits (0.01ppm and 0.04-0.06ppm). Also the research revealed that none of the ambient pollutants at the point source met the WHO and FEPA limits.

The above researches itemize the contribution of various researchers in the evaluation of the impact of combustion activities on the indoor air quality and as well as the indoor environmental condition. And at this point it can be seen that combustion is a major source of pollutants generation in the environment. Thus, this research work seeks to evaluate the impact of the combustion activities in the laboratories on the indoor air quality of the laboratories.

2.13 HVAC REQUIREMENT FOR A LABORATORY

Several write ups have being done with regards to the HVAC requirement for a laboratory; the emphases were on the energy usage common to laboratories as well as the comfort requirement. 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 to energy efficiency. That's no longer true, and designers must account for operating costs as well as functionality.

A typical 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, a voluntary partnership program dedicated to improving the environmental performance of U.S. laboratories. The majority of this HVAC energy consumption originates from cooling (22%) and ventilation (44%) loads that help the laboratory function safely (Lindsay, 2010).

The high energy use can be attributed to high outside air requirements, large internal heat gains from laboratory equipment, and, in many cases, continuous hours of operation, (Knol etal, 2009). With a push toward a more energy-efficient laboratory environment, vendors are developing new technologies or adapting older ones to help reduce HVAC energy consumption. Lindsay's emphasizes was more in the line with HVAC requirement for laboratories as energy saving measure and not on the adequacy of indoor air quality for laboratories.

Several standards have specified their requirement in ensuring adequate indoor air quality especially in the aspect of air circulation and fume hood usage. These standards were published in the 'Laboratory Standard and Guidelines' (2002) comprising of various Standards and their specification for adequate indoor air quality within the laboratory. The various requirements are given in the Table 2.3;

Table 2.2: Standards on the use of Fume hoods

S/N	STANDARD	REQUIREMENT	
1	NEPA45	i)	Section 6.4.6 stipulates that Laboratory hood face velocities and exhaust volumes shall sufficient to contain contaminants generated within the hood outside of the laboratory building. The hood shall provide containment of the possible hazards and protection for personnel at all times when chemical are present in the hood'
		ii)	Section .6.4.6 stipulates that fume hood containment can be evaluated using the procedures contained in the ASHRAE 11, 'method of testing performance of laboratory fume hoods'. Face velocity of 0.4m/sec (80ft/min to 10ft/min) generally provide containment if the hood location requirements and laboratory ventilation criteria of this standard are met'
2	ANSI/AIHA	i)	Section 5.7 each hood shall maintain an average face velocity of 80-120fpm with no face velocity measurement more than plus or minus 20% of the average
		ii)	'adequate laboratory fume hoods, special purpose hoods, or other controls shall be used when there is a likelihood of employee overexposure to air contaminants generated by a laboratory activity
3	Federal Register-OSHA	i)	Each fume hood should have a continuo monitoring device to allow convenient confirmation of adequate hood performance before use
		ii)	For a prudent practice, it should be ensured that a continuous monitoring device to allow convenient confirmation of adequate hood performance before use
		iii)	'leave the hood 'on' when it is not in active use if toxic substances are stored in it or if it is uncertain whether adequate general laboratory ventilation will be maintained when it is 'off'
4	SEFA 1.2	i)	Section 5. 2 'A fume hood velocity of 100fpm is considered acceptable in standard practice. In certain situation face velocity of up to 125fpm or as low as 75fpm may be acceptable to meet required capture velocity of the fume hood '

Source: laboratory Standard and Guideline ,2002

Table 2.3 Standards for air recirculation in the laboratory

S/N	STANDARDS	REQUIREMENT	
1	Federal Register-OSHA	i)	Laboratories should continually replaced , preventing increase or of air concentration of toxic substances during the working day
		ii)	All air from chemical laboratories should be exhausted outdoors and not recirculated. Thus air pressure in chemical laboratories should be negative with respect to the rest of the building unless laboratory is also a clean room.
2	ASHRAE handbook	i)	Laboratories in which chemicals and compressed gases are used generally require non recircuilating or 100% outside air systems. The sestion of 100% outside air supply systems versus return air sytem should be made as part of the hazard assessment process, which discussed in section on harzard assessment. A 100%outside air system must have a very wide range of heating and colling capacity, which requires special deign and control
		ii)	Supply air system for laboratories include both constant volume and variable volume system that incorporate either single-duct reheat or dual-duct configurations, with distribution through low, medium or high pressure ducts
3	NFPA 45	i)	Section 6.3.1 'laboratory ventilation system shall be designed to ensure that chemicals origination from the laboratory shall not be recirculated. The release of chemicals into the laboratory shall be controlled by enclosure(s) or captured to prevent any flammable and/or combustible concentration of vapor from reaching any source of ignition'
4	Industrial ventilation-ACGIH	Where large amount of air are exhausted from a room or building in order to remove particulate gases, fumes or vapors an equivalent amount of fresh tempered replacement air must be supplied to the room. If the amount of replacement air is large, the cost of energy to condition the air can be very high. Recirculation of the exhaust air after thorough cleaning is one method that can reduce the amount of energy consumed. Acceptance of such recirculating systems will depend on the degree of health hazard associated with the particulate contaminant being exhausted as well as other safety technical and economic factors.	
5	ANSI/AIHA Z9.5	i)	Section 4.10.2 'air exhaust from the general laboratory space(as distinguished from the exhaust hoods) shall not be recirculated unless one of the following set of criteria is

		met a) Criteria A 1) There is no extremely dangerous or life-threatening material used in the laboratory 2) The concentration of air contaminants generated by maximum credible accident will be lower than short-term exposure limits 3) The system serving the exhaust hood is provided with installed spares, emergency powe, and other reliability features as necessary b) Criteria B 1) Recirculated air is treated to reduce contaminant concentration 2) Recirculated air is monitored continuously for contaminant concentration or provided with a secondary backup air cleaning devices that also serve as a mo itor(i.e a HEPA filter in a series with a less efficient filter, for particulate contamination only) 3) Air cleaning and monitoring equipement is maintained and calibrated under a preventive maintenance programme 4) A bypass to divert the circulated air to atmosphere is provided
6	NIH Research Laboratory	i) Section D7.6 'laboratory HVAC system shall utilize 100% outdoor air, conditioned air by central station air handling systems to offset exhaust air requirements. Laboratory supply air shall be recirculated or reused for other ventilation needs'

Source: laboratory Standard and Guideline ,2002

CHAPTER THREE

RESEARCH METHODS

The research was pursued through field work involving experimentation and perception survey. The experimentation entails the use of equipment (a combustion gas analyzer) to measure quantities of combustion pollutants in the indoor air of selected laboratories. The perception survey entails the use of structured questionnaire to access the view of users of the laboratories on the indoor air quality of the laboratories where combustion takes place. Both the experimentation and perception survey were based on an in-depth knowledge of the subject area obtained through literature review.

3.1 SELECTION OF LABORATORIES FOR THE STUDY

This study was undertaken in order to establish the effects of combustion pollutants on the indoor air quality of laboratories, thus the laboratories in the Department of Chemistry Ahmadu Bello University were adopted for this purpose. The Department of Chemistry is known for its large number of laboratories of varying capacities and purposes ranging from teaching to research purposes. These laboratories also have varying number of Student and teachers using them at the same time. Among the laboratories of the Departments are:

i) Organic laboratory (with a capacity of about ten students)

ii) The main teaching laboratory (with a capacity of over a hundred students per sitting)

iii) Inorganic laboratory

iv) The Master Student laboratory (with a capacity of about fifty students and two staff)

v) The Multi-user laboratories (with a capacity over a hundred students and six staff)

vi) The School of Basic (SBRS) lab also used by 100level students in the faculty

vii) Physical Chemistry Laboratories (PCL)

However, not all the above itemized laboratories entail chemical processes requiring combustion activities. The inorganic laboratory for example houses process that does not require combustion; others however have sufficient combustion activities going on in the laboratories as the chemical processes are being organized. Thus, for the purpose of this research work all the above listed laboratories will be studied with the exception of the organic laboratory.

3.2 THE EXPERIMENTAL WORK

The experimental work entails the use of a gas analyzer for the measuring the combustion pollutant generated in the laboratories under consideration. This section describes the mode of measurement, the unit of the measurement, a description of gas analyzer employed for this purpose, the measurement process/procedure, and the precautions ensured. Hence below is the description of the experimental approach:

3.2.1 Mode of Measurement

The measurement of the combustion generated pollutants was done with the help of a sensitive gas analyzers, the "IMR 1400C" in order to establish the presence and amount of the combustion pollutants present in the air during the combustion processes. The processes of measurement involve:

3.2.1 Description of IMR 1400C Gas Analyzer

The IMR 1400C gas analyzer is a state of the art combustion gas analyzer. It measure and calculates the amount of the following;

i) oxygen (O_2)

ii) carbon monoxide (CO)

iii) Carbon dioxide (CO_2)

iv) Oxides of Nitrogen (NO_x)

v) Sulfur dioxide (SO_2)

Source: IMR Environmental Equipment, Inc.,2012)
Fig 3.1 The IMR 1400C Combustion Gas analyzer

The IMR 1400 has the following technical data that expresses its resolution as well as its degree of accuracy for each gas it measures as given the Table 3.1

Table 3.1: Technical Data of IMR 1400 Gas Analyzer

S/N	PARAMETER	PRINCIPLE	RESOLUTION	ACCURACY	RANGE
1	O_2 Oxygen	Electro-chemical	0.1 Vol.%	± 0.2 %	0-20.9Vol. %
2	CO Carbon monoxide	Electro-chemical	1 ppm	Z	0-2,000 ppm
3	CO Carbon monoxide	Electro-chemical	1 ppm	Z	O-4.000 Vol.%
4	NO Nitric oxide	Electro-chemical	1 ppm	Z	0-2,000 ppm
5	NO_2 Nitric dioxide	Electro-chemical	1 ppm	Z	0- 100 ppm
6	SO_2 Sulfur dioxide	Electro-chemical	1 ppm	Z	0-4,000 ppm
7	TG Gas temperature	NiCr-Ni thermocouple	1K	± 2 %	-4°F..2192°F - 20°C..1200°C
8	TA Air temperature.	Semiconductor	1K	± 0.5 K	4°F..248°F - 20°C..120°C
9	P Draft	Solid state	0.004" H2O 0.01 hPa	± 2 %	- 12"H2O/+20 "H2O - 30hPa/+50hPa
10	CO_2 Carbon dioxide	Calculation	0.1 Vol.%	± 2 %	0- CO_2 max
11	Combustion Efficiency / ETA	Calculation	1%	± 0.5 %	0-99,9 %
12	Losses / qA	Calculation	1%	± 0.5 %	0-99,9 %
13	Excess air / LAMBDA	Calculation	1%	± 2 %	1,0-9,99
14	Soot	Filter paper			

Other range is available upon request
Z= 0-20% of the measuring range +/-1% of the maximum value
Z= 21-100% of the measuring range +/-5% of the display value
4 sensors are the maximum for the IMR 100PS
Source: IMR Environmental Equipment, Inc,2012

3.2.2 Measurement Using the IMR 1400C

The indoor air pollutants from combustion activities were measured with the aid of the IMR 1400C gas analyzer. The sampling probe was held at 1m height in the laboratory for 2minutes after the 180 seconds calibration of the analyzer and the quantity of pollutants present were measured. The maximum and minimum measurements of the pollutants were recorded. Measurements were carried out for the laboratories (two not more than three hours before the combustion activity, two during the combustion activities and the last two not more than three hours after the combustion activity). IMR Environmental Equipment, Inc.(2012). The same process was repeated for all the laboratories under study with.

IMR 1400C combustion gas analyzer calibrates in 180second for startup of the analyzer and for 60seconds for the recalibration for subsequent measurements. These were to ensure accuracy of the result. Results qualities for the samples were ensured by repetitive measurement and adherence to the requirement for measurement of the pollutants before, during and after the combustion activity.

3.2.3 Quantities and Units of Measure for Exposure and Emission Monitoring

Since very small accumulations of the described pollutants are enough to cause health risks, the concentrations that are to be measured in case of air pollution are also very small. They are either indicated in volume parts or in mass per volume of air.

Units of volume concentration are expressed in ppm (1 part per million = 0,0001 %). For mass concentration mg/m^3 is used. The value in ppm equals the value in ml/m^3.

1 Vol.-% = 10 000 ppm = 10 000 ml/m^3

3.2.4 Number of Measurement Points within the Laboratories

In accordance with the Guide on Indoor Air Quality Certification Scheme for Offices and Public Places (2003) and with provision of the ASHRAE standard 62 (2002) the number of sampling points will be taken based on the provision of the standard given in Table 3.2

Table 3.2: Number of Sampling Point in the Laboratory for the Pollutants Measurement

S/N	Total floor area of laboratory to be studied (m^2)	Minimum number of sampling point
1	<, 3000	1 per 500m^2
2	3000-<5000	8
3	5000-<10000	12
4	10000-<15000	15
5	15000-<20000	18
6	20000<30000	21
7	≥30000	1 per 200m^2

Source: Guide on Indoor Air Quality Certification, 2003

Based on the above table the floor area of each laboratory under consideration will be measure and the appropriate number of sampling point i.e. positioning of the gas measuring instrument will be employed.

3.3 PERCEPTION SURVEY

The field work of this research was conducted using various research instruments, each adopted to meet a particular research need. The various instruments and its application are explained below:

3.3.1 Tools for Data Collection.

In addition to the literature review and the experimental process other data collection instruments such as a well structured questionnaire and a checklist was also

adopted. The details of the sample size and the sampling method using the field survey are given below:

3.3.1 Questionnaire

The questionnaires were administered to the staff and the students. The questionnaire sought information in the following aspects pertaining to the effects of the combustion generated pollutants on the indoor air quality of the laboratories

i. The duration of time spent by staff and students in the laboratory

ii. Observations on indicators of pollution due to combustion activities.

iii. The opinion of the respondents on the measures that can lead to improved indoor air quality in the laboratories.

With regards to the sampling size in the distribution of the questionnaire, the sampling size will be determined based on the formula below considering the fact that the targeted population is unknown. (IWSD, 2003 in Macdonald, 2006)

$$\mathbf{n= (z^2pq)/d^2}$$

Where;

n = the desired sample size

z = the ordinate on the Normal curve corresponding to α or the standard normal deviate, usually any of the following determined based on the 'margin error formula'

i. A 90% level of confidence has $\alpha = 0.10$ and critical value of $z_{\alpha/2} = 1.64$.

ii. A 95% level of confidence has $\alpha = 0.05$ and critical value of $z_{\alpha/2} = 1.96$.

iii. A 99% level of confidence has $\alpha = 0.01$ and critical value of $z_{\alpha/2} = 2.58$.

iv. A 99.5% level of confidence has $\alpha = 0.005$ and critical value of $z_{\alpha/2} = 2.81$.

P = the proportion in the target population estimated to have particular characteristic (normal between the range of 0.1 - 0.5)

q = 1.0-p

d = degree of accuracy corresponding to the confidence level and Z selected.

For the purpose of this study, a confidence level of 95% will be adopted owing to the fact that the questionnaire is geared towards evaluating perception of the respondents to feeling on the indoor air quality.

Consequently, the sample size is determined as thus,

z = 1.96, d = 0.05 where p = 0.9, q =0.1

Hence,

Sample size n = $((1.96)^2 \times 0.9 \times 0.1)/ (0.05)^2$ =

Thus the study will administer 138 questionnaires.

The sampling technique adopted for the research was a random sampling owing to the fact that both the students and staff have their various opinions on their perception to the indoor air quality of the laboratory before, during and after combustion.

3.3.2 Checklist

The checklist was also prepared to collect all the relevant information of the laboratories under study. Such information's like the presence of the necessary Heating Ventilation and Air Conditioning System; the presence and functional state of the fume

boxes 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

3.4 DATA ANALYSIS

The data collected for this study was subjected to various statistical analyses using the computer based software "Statistical Package of Social Sciences" (SPSS). The results of the analysis are presented in the forms of table for the purpose of easy comparism and clear expression of the findings. Relative importance indices (RII) was also used to rate the health symptoms of the combustion generated pollutants on the indoor air quality. The Relative Importance Index (RII) was calculated for each document according to their frequency of use as suggested for use by Memon et al, (2006) and Othman et al, (2005)

Relative importance index was used in the study to rank the factors relating to the availability of housing financing funds.

Relative Importance Index (RII) $= \frac{\sum fx}{\sum f} \times \frac{1}{k}$

Where,

$\sum$fx = is the total weight given to each attributes by the respondents.

$\sum$f = is the total number or respondents in the sample.

K = is the highest weight on the likert scale.

Results are classified into three categories as follows (Othman et al, 2005) when;

RII<0.60 -it indicates low frequency in use

0.60≤RII<0.80 -it indicates high frequency in use.

RII≥0.80 –it indicates very high frequency in use.

Experimental results are presented in adequate table and with the adequate unit of measurement for a clear expression of the finding.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 EXPERIMENTAL WORK

The combustion generated pollutants were measured in the laboratories prior to the combustion process, during and after the combustion process for different points or spots within the laboratory. A total of six (6) laboratories were studied in three session of experiments and the result of the combustion generated pollutants measured are presented in Tables 4.1 to Table 4.6 in accordance to the sessions of measurement

4.1.1 Result of the Combustion Pollutant Measurements

Table 4.1: Result of the Combustion Pollutant Measurement in Chemistry Lab I along with ASHRAE Requirement and NAAQS standard

Session		Chemistry lab I									
	Pollutants(O2 in% others in ppm)	**Measurement 3hours Before Combustion**			**Measurement During Combustion**			**Measurement 3hours After Combustion**			**ASHRAE ACCEPTABLE LIMIT(O2 in% others in ppm)**
		A1	**A2**	**A3**	**B1**	B2	**B3**	**C1**	**C2**	**C3**	
1	**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
	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	1.1	2.1	3.2	4.2	1.0	0	0.0	≤ 1000ppm
2	**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	06	24	11	11	03	02	07	≤9ppm
	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	1.0	3.2	1.0	1.0	2.1	1.0	1.0	1.0	≤ 1000ppm
3	**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	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, (2013)

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

From Table 4.1, it can be observed that CO often exceeded the permissible limit especially during the combustion process rising up to (45ppm against the 9ppm limit). It

can also be observed that the oxygen levels were at the critical level and at few points even below the limit, making the tendency of incomplete combustion higher.

Table 4.2: Result of the Combustion Pollutant Measurement SBRS LAB II along with ASHRAE Requirement and NAAQS standard

Session	Pollutants(O2 in% others in ppm)	SBRS LAB II									ASHRAE ACCEPTABLE LIMIT(O2 in% others in ppm)
		Measurement 3hours Before Combustion			Measurement During Combustion			Measurement 3hours After Combustion			
		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	2.1	4.2	2.0	21.	1.0	2.1	1.0	2.3	1.0	≤ 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	33	27	18	07	03	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	2.1	4.2	1.0	2.2	1.0	1.0	2.1	1.0	2.0	≤ 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	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, (2013)

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

From Table 4.2, it can be observed that the most reoccurring pollutant that exceeds the limit is CO especially during the combustion process rising up to (45ppm). The presentation in the table above shows the measurement of the pollutants at three different points before the combustion activities as well as during and after the combustion activities. The trend of rise and fall of the amount of the pollutants within the interior are also presented in the table. These measurements are peculiar to the SBRS lab II

Table 4.3: Result of the Combustion Pollutant Measurement IN SBRS LAB III **along with ASHRAE Requirement and NAAQS standard**

Session	Pollutants(O2 in% others in ppm)	SBRS LAB III									ASHRAE ACCEPTABLE LIMIT(O2 in% others in ppm)
		Measurement 3hours Before Combustion			Measurement During Combustion			Measurement 3hours After Combustion			
		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	15	11	09	09	04	≤9ppm
2	**NOx**	0.0	2.0	0.0	1.0	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	1.1	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	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		≤ 0.14ppm
	CO_2	4.2	3.1	1.0	3.2	5.6	3.2	2.1	3.2	1.2	≤ 1000ppm

Source: Field Survey, (2013)

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

The table 4.3 presents the amount of pollutants measured at three different points within the chemistry SBRS Lab III before, during and after the combustion activities in the laboratory. Form the Table 4.3, it can be discovered 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 the there was no SO pollutant recorded throughout first session of experimentation and there is an unstable level of oxygen usually falling below the limit.

Table 4.4: Result of the Combustion Pollutant Measurement IN CHEMISTRY MULTI-PURPOSE LAB along with ASHRAE Requirement and NAAQS standard

Session		**CHEMISTRY MULTI-PURPOSE LAB**									
	Pollutants(O2 in% others in ppm)	**Measurement 3hours Before Combustion**			**Measurement During Combustion**			**Measurement 3hours After Combustion**			**ASHRAE ACCEPTABLE LIMIT(O2 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	33	08	09	02	06	≤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	2.1	3.2	1.0	3.2	5.6	3.2	2.1	1.0	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	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, (2013)

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

The table 4.4 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. Form the Table 4.4, it can be discovered that CO is the pollutant that is more generated even at the three different sessions of the experiments.

Table 4.5: Result of the Combustion Pollutant Measurement PHYSICAL CHEMISTRY LAB Along With ASHRAE Requirement and NAAQS Standard

Session	Pollutants(O2 in% others in ppm)	PHYSICAL CHEMISTRY LAB									
		Measurement 3hours Before Combustion			Measurement During Combustion			Measurement 3hours After Combustion			ASHRAE ACCEPTABLE LIMIT(O2 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	11	14	36	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, (2013)

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

The Table 4.5 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. Form the Table 4.5, it can be discovered that similar to the other laboratories studied, CO is the pollutant that is frequently generated beyond the limit provision (9ppm). It can also be observed that the oxygen content as measured was not consistent throughout the measurement.

Table 4.6: Result of the Combustion Pollutant Measurement CHEMISTRY MASTERS STUDENT LAB along with ASHRAE Requirement and NAAQS standard

Session	Pollutants(O2 in% others in ppm)	CHEMISTRY MASTERS STUDENT LAB									
		Measurement 3hours Before Combustion			Measurement During Combustion			Measurement 3hours After Combustion			ASHRAE ACCEPTABLE LIMIT (O2 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	28	23	11	06	02	03	≤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, (2013)

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

The table 4.6 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 discovered that CO is the pollutant that is more generated even at the three different sessions of the experiments.

4.2 THE PERCEPTION SURVEY

4.2.1 Questionnaires Survey Result and Analysis

A total of one hundred and forty questionnaires were administered to both the staff and students in the area of study. The percentages of responses are presented in Table 4.7 below. Form the table it can be gathered that a total of one hundred and twenty-seven questions were received adequately filled giving a percentage response of 90.7%.

Table 4.7 Questionnaire administered

Questionnaires	Frequency	Percentage of (%)
Number returned	115	90.7
Numbers not returned	12	9.3
Total	140	100

Source: Field Survey, (2013)

4.2.2 Respondents' Profile

From the result of the analysis of the respondents opinion conducted, the profile of the respondents is presented in Table 4.8

Table 4.8 Respondents' Profile

S/N	Variable	Option	Frequency (No)	Percentage (%)
1	Sex:	a) Male	86	67.7
		b) Female	41	32.3
		Total	127	100
2	Status:	a) Staff	11	8.7
		b) Student	116	91.3
		Total	127	100
3	Age(years) Range:	a) Below 20yrs	22	17.3
		b) 21-30yrs	78	61.4
		c) 31-40yrs	21	16.5
		d) 41yrs and above	6	4.7
		Total	127	100

Source: Field Survey, (2013)

From the table above, it can be established that there are more male respondents (67.7%) than female (23.3%) respondents. Also it can be deduced that the age bracket with the highest frequency observed was 21-30years, (61.4%) this was followed closely by the age bracket below 20years (17.3%).

4.2.3 Frequency Of Use Of Laboratory

The relevance of the laboratories was assessed alongside the frequency of use of the laboratories by the respondents the result of the analysis is presented in the Table 4.9 below:

Table 4.9 Frequency of Laboratory Use

S/N	Variable	Option	Frequency	Percentage (%)
1	Use of laboratory:	a) Yes	127	100
		b) No	0	0
		Total	**127**	**100**
2	Frequency of laboratory use:	a) Once a week	22	17.3
		b) Twice a week	21	16.5
		c) Daily excluding weekends	76	59.8
		d) Daily including week day	8	6.3
		Total	**127**	**100**
3	Hours Spent Laboratory Per Day:	a) 0-2hrs	58	45.7
		e) 3-4hrs	35	27.6
		f) 5-6hrs	34	26.8
		Total	127	100

Source: Field Survey, (2013)

From Table 4.9, it is observed that all the respondents (100%) make use of the laboratory; however with regards to the frequency of use within the week it is observed that most of the respondents use the laboratory daily excluding weekends (59.8%). Also with duration of time spent in the laboratory by the respondents, it is observed that the time interval with the highest frequency is 0-2hrs corresponding to a percentage of 45.7%.

4.2.4 Combustion in Laboratory and Mode of Heat Generation

Combustion activities in the laboratories; the means of heat generation and the presence fume hood installation and their functionality was also assess, Table 4.10 below presents the respondents opinions

Table 4.10 Combustion, Heat Source and the Presence of Fume Hood in Laboratories

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, (2013)

From Table 4.10, it is observed that majority of the respondents opined that their work entails combustion (74.0%). Also the major heat generating device frequently used in the laboratories as opined the respondent is the gas burner (70.1%). With regard to the presence of a functional fume hood installation, the majority of the respondent were not aware of the presence of a fume hood and it functional status; this corresponds to a percentage of 47.2% of the respondents.

4.2.5 Combustion And Ventilation In Laboratories

The perceptions of the respondents were also assessed with regards to the impact of combustion activities in the laboratory as well as the evaluation of the adequacy of the ventilation system. Table 4.11 below, presents the result of the assessment

Table 4.11 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	Process That Posses 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, (2013)

It can be observed from Table 4.11, that combustion is a source of discomfort, as observed by 92.1% who opined that it was a source of discomfort. Also, it can be observed that of all the processes identified combustion was more discomforting (54.3%). With regards to the ventilation system, it obvious that the ventilation is not adequate as 79.5% of the respondent attested to it.

4.2.6 Health Symptoms of Poor Indoor Air Quality

Several health symptoms of a poor indoor air quality were assessed and the respondents ranked these symptoms. Table 4.12, presents the ranking of the various health symptoms that serve as indicators to a poor indoor air quality.

Table 4.12: Ranking Of the Health Symptoms of Poor Indoor Air Quality

	FREQUENCY					(∑f)	∑fx	MEAN	RII	RANK
SYMPTOM	**1**	**2**	**3**	**4**	**5**					
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
Heart Burn	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, (2013)

Where: 1 =strongly disagree, 2 = disagree, 3 =undeceived, 4= agree, 5=strongly agree

From Table 4.12, it is observed that the respondents ranked fatigue (with RII= 0.81) was ranked as the most reoccurring health symptom indicating a poor indoor quality. Also it is observed that only symptoms like fainting and Nausea had a relative importance index less than 0.6, indicating that they are not a commonly observed symptom. Also from the mean values, it can be deduced that the value were closer to the linkert weighting of four (4) an indication that the respondents general opinion agrees that the symptoms were truly an indication to poor indoor air

4.2.7 HVAC and Combustion Related Factors That Are the Cause for Poor Indoor Air Quality in Laboratories

The questionnaire also sort the opinion of the respondents with regards to the Heating Ventilation and Air Conditioning (HVAC) system as well as combustion on how they contribute to the poor indoor air quality of laboratories. The opinion and ranking of the respondent are presented in Table 4.13 below

Table 4.13: Ranking of the Causes of Poor Indoor Air Quality

	FREQUENCY					(∑f)	∑fx	MEAN	RII	RANK
CAUSES	**1**	**2**	**3**	**4**	**5**					
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
Non Functional Fume Hoods	12	13	12	68	22	127	456	3.59	0.72	5TH
Unvented Combustion Equipment	58	20	13	27	09	127	290	2.29	0.46	9TH
Prolonged And Reoccurring Combustion	05	20	12	58	30	127	463	3.65	0.73	4TH
Over Crowding In Labs	-	-	07	40	80	127	581	4.57	0.91	1ST
Faulty Burners	04	40	62	21	-	127	354	2.79	0.56	7TH
Too Humid Air	03	26	70	28	-	127	377	2.97	0.59	6TH
Poor Air Movement	-	54	67	06	-	127	333	2.62	0.52	8TH

Source: Field Survey, (2013)

Where: 1= not a cause, 2= not a major cause, 3= barely a cause, 4=a cause, 5=always a cause

From Table 4.13, it can be observed that overcrowding in labs (RII=0.91) was ranked the first cause of poor indoor air quality, this followed closely by combustion activities (RII=0.89). It can also be seen that other factors like: faulty burners, too humid air and unvented combustion though a factor but was not with intense effect owing to their relative importance index (RII), which are below 0.6. with regards to the mean, it can be observed that the values were closer to the weighting four(4) an indication, that the respondents opinion was that the identified factor are all causes of poor indoor air quality. The Table also gives a frequency break down on each of the options as chosen by the respondents.

4.2.8 Remedial Action to Poor Indoor Air Quality In Laboratories

Table 4.14 gives the respondents ranking of the various remedial measures to the poor indoor air quality identified; it also gives the percentage response per option as well as the mean and standard deviation as shown below:

Table 4.14: Ranking of the Remedy to the Poor Indoor Air Quality

	FREQUENCY					(∑f)	∑fx	MEAN	RII	RANK
Remedy	**1**	**2**	**3**	**4**	**5**					
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 air flow during combustion	-	13	14	28	72	127	540	4.25	0.85	2nd
Use of excellent combustion equipments	14	-	21	32	60	127	505	3.98	0.79	4th
Orientation of both staff and student on the danger of poor indoor air quality	32	-	9	28	58	127	461	3.63	0.73	5th

Source: Field Survey, (2013)

Where: 1 =not Effective, 2= no effect, 3=slightly effective, 4=Effective, 5=very effective

From the Table 4.14, it can be observed that the highest rank remedy to the poor indoor air quality by the respondents is the provision of adequate Heating Ventilation and Air Conditioning System(RII= 0.87). also from the mean values, it can be established that in the general the respondents opined that the identified remedy were all feasible options as the value of the mean is closer to the likert weighting of four(4).

4.2.9 Checklist Survey

The result of the checklist survey conducted is presented in Table 4.15. It can be established that most of the laboratory satisfy the condition of the General observation with the exception of chemistry Lab II and the multipurpose Lab, where moulds were discovered at the walls and ceilings. Similarly, the ventilation system of the laboratories where satisfactory with the exception of the chemistry lab II where there exist a wall barrier to the air intakes and the physical chemistry lab I where there are is exist no extract duct. It was also discovered that all the laboratories studies do not have air filters installed in them.

Table 4.15 Result of the Checklist Survey

S/N	Variable		Option	Remark	Exceptions
1	General observation(walls, ceiling and floors):	a)	Free from mould	Satisfactory	None
		b)	Flat surface dust free	Satisfactory	None
		c)	Diffusers are unobstructed	Satisfactory	None
		d)	Walls and ceilings free from mould	Satisfactory	Chemistry lab II and the multipurpose lab
2	Ventilation System (HVAC)	a)	Adequate outdoor air intake	Satisfactory	Chemistry lab III
		b)	Air intake clear off pollutants	Satisfactory	None
		c)	Cleanliness of duct	Satisfactory	Physical chemistry lab I, SBRS lab II
		d)	Ventilation shut-down	Not satisfactory	None
		e)	Presence of air filter	Absent	None
3	General Maintenance Design:	a)	Windows can be opened	Satisfactory	None
		b)	Presence of odour	Satisfactory	Masters lab
		c)	Number of occupants to size of interior	Interior over crowded	None
4	Humidifier :	a)	Presence of fan	Satisfactory	None
		b)	Use of volatile chemicals for humidifier	None	None

Source: Field Survey, (2013)

4.3 DISCUSSION OF RESULTS

The discussions are based on the result of the analysis of the respondents' opinions and the experimental as well as the records gotten from the checklist survey laboratories under study.

4.3.1 Combustion Generated Pollutants

The study revealed that combustion generated indoor air pollutant in the laboratory where more of CO and NOx (Table 4.4) the mean value of SO where within the normal range as specified by the ASHRAE 62 along side with requirement for WHO and FEMA limits. However the limit for pollutant like CO were above the limit specified

by this standard thus making exposure to such gaseous pollutant very hazardous to the health of both the students and the staff. From the result of the measure (Table 4.1- Table 4.6) it can be discovered that during the combustion activities, the amount of CO increases far beyond the NAAQS standard of 9ppm for all the labs with the exception of the Masters lab Where a water bath is used as a source of heat generation as against others that were purely gas burners. Also from the result it can be established that the chemistry multi-purpose lab had the highest amount of pollutants owing to the population of students and the non-functional fume hoods.

Also from the experimental result, it can be established that the oxygen level at the laboratories were at the critical limit (20.9%) with the value dropping at certain 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)

4.3.2 Profile of Respondents

Table 4.8 shows that there are more male (67.7%) than female (23.3%) respondents and that the predominant age bracket is 21-30yrs (61.4%). This suggests early exposure of the youth to potential health hazards and call for attention.

4.3.3 Use of Laboratory, Combustion and Ventilation in Laboratories

The study establishes that the laboratory is a basic requirement for any study institution (Table 4.9). In line with this, the study also reveals that most laboratory users have need to spend between about 2-3hours daily excluding weekends as presented in Table 4.9. The study also established that there are no adequate ventilation in the laboratories studied especially during combustion processes as shown in Table 4.5.

Similarly, the study reveals that the major source of heating generating device in the laboratories were gas burners and to a large extent the functionality of the fume hoods were in doubt as most of the respondents cannot attest to their functionality as shown in Table 4.10. However, the checklist revealed that in the case of scarcity of gas for combustion process, water bath as shown in the appendix Fig 11 were employed as an alternative heater.

4.3.4 Health Symptom of a Poor Indoor Air Quality

The study established that fatigue was the most predominant heath symptom of a poor indoor quality especially due to the presence of combustion pollutants. Also with reference to the Relative Importance Index (RII) value of fainting and Nausea which was less than 0.6, it is a clear indication that other health symptoms identified were symptom of a poor indoor quality with the exception of these two.

4.3.5 Causes of poor indoor air quality and the remedy

The study revealed that in addition to combustion activities being a major cause of poor indoor air quality, overcrowded arrangement of students in the laboratory is also a major contributor to the poor indoor air quality as shown in Table 4.13. Other major causes of poor indoor air quality are: non functional fume hoods, prolonged and reoccurring combustion activities. However other factors like the humid air were not a major contributor to the poor indoor air quality in laboratories. With regard to the remedy to the poor indoor air quality, the study establishes that the following are possible measures that can be adopted:, the provision of adequate HVAC system, use and maintenance of functional fume hoods, orientation of staff on the danger of poor indoor

air quality to health and also to avoiding overcrowding of student working in the laboratory. This can also be seen in Table 4.14

4.3.6 HVAC Status of the Laboratories

The study revealed that some of the laboratories (Chemistry Lab II and the multipurpose) laboratory did not meet the requirement of the Heating Ventilation and Air conditioning (HVAC) requirement. The result of the checklist survey in Table 4.15 shows other HVAC requirements and the status of the laboratories studied. Form the table, it can be observed that the most predominant lapse found in the HVAC systems of the laboratories are; the absence of cleaning duct, absence and in some cases none functional fume ducts and absence of air filters. This account for the critical state of oxygen level identified from the measurements

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY:

The following are the summaries of the findings:

i) Carbon -monoxide (CO) occurring as the major pollutants that exceeds the ASHRAE and NAAQS standard of 9ppm reaching up to 45ppm at certain points during combustion activities in the laboratories, with particular reference to "SBRS lab III" and Chemistry Multi-Purpose lab. Other pollutants like; NO_x and SO_2 where observed to be within the limits

ii) Oxygen discovered to be at the critical level of 20.9% based on ASREA and NAAQS standard and even falling below the limits as low as 20.4% at some points in the laboratories.

iii) Laboratory is a basic requirement for the teaching and learning processes in the university this evident from the frequency of use of laboratory(daily excluding weekends) and the duration of hours spent in the laboratory(2-4hr) by the respondent (staff and student)

iv) Combustion activities is practically unavoidable for teaching and learning activities, and the major source of heat generation for the combustion activities were with the use of gas burners except in few cases where there is limited supply of gas the water bath is used as an alternative heat generating source which also depends on the type of experiment performed

v) Adequate ventilation in some laboratories like; 'chemistry SBRS lab II and III'. However, other laboratories studied were not well ventilated due to the absence of fume hoods as in the case of' Chemistry Lab I' and none functional fume hoods in the other laboratories.

vi) Combustion among other processes in the laboratory cause more discomfort and affects the indoor air quality the most

vii) Fatigue is one of the most reoccurring health symptom 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.

viii) In addition to combustion activities as a major cause of poor indoor air quality, some other factors that intensify the effect of combustion activities in reducing the indoor air quality are: congestion in the laboratories, inadequate ventilation system and faulty heat generation devices

5.2 CONCLUSION

From the ongoing, the following are concluded:

Of the three major combustion pollutants investigated, Carbon-monoxide (CO) with mean concentration of (23.67ppm) exceeded the ASHRAE Standard 62 limit of 9.0ppm. oxide of Nitrogen (NO_x) and Sulphur-dioxide SO_2 were found to be within the prescribed limits of (0.0053ppm) and (0.14ppm) respectively.

The absence and none functional state of some Heating Ventilation Air Condition (HVAC) requirement of a laboratory like; fume hood, air extracts, and adequate air

opening, void of obstruction account for the high concentration of the combustion pollutants during combustion activities in the laboratories studied

Similarly, in adequate HVAC requirement can tantamount to insufficient oxygen, with particular reference to SBRS lab III, accounting for the critical state of oxygen during combustion(Oxygen been at 20.9%)

In addition to combustion activities in the absence of adequate HVAC system, other activities that increase the generation of combustion pollutants in the laboratories include the use of faulty burners, prolong and reoccurring combustions and congestion in laboratories due to overpopulation of laboratory users.

The users identified the following symptoms; fatigue, headache, sinus congestion, coughing and sneezing, dizziness, heart burn, nausea and blurred vision; as health symptoms of poor indoor air quality resulting from the presence of combustion pollutants during combustion activities in the laboratories

5.2 RECOMMENDATION

The following are recommended:

i) It is also recommended that fume hoods be installed in the laboratories that are without fume hoods such as the Chemistry Lab I hood. This is to take care of the gaseous pollutants from combustion activities

ii) Adequate provision and maintenance of the Heating Ventilation and Air Conditioning (HVAC) system of the laboratories particularly the fume hoods

iii) The school authority as a matter of urgency should try and construct new laboratories to address the challenges from congestion in the laboratories. This will also help in accommodating the teaching and learning of the students enrolled

iv) Creation of awareness on the deadly health consequences of individuals exposure to combustion indoor pollutants among staff and students within the institution and even in the general public

REFRENCES:

American Lung Association (1992). "Indoor Air Pollution Fact Sheet - Combustion Products". Publication No. 1182C.

American Thoracic Society, (1990) "Report of the ATS Workshop on Environmental Controls and Lung Disease, Santa Fe, New Mexico, March 24-26, 1988." *American Review of Respiratory Disease*; 142:915-39.

ANSI Z223.1-2006/NFPA 54-2009. National Fuel Gas Code. New York, NY: America National Standards Institute, and Quincy, MA: National Fire Protection Association.

ANSI Z21.11.2.-2007. ANSI Standard for Gas-Fired Room Heaters, Vol. II, Unvented Room Heaters. New York, NY: American National Standards Institute.

ANSI Z21.1-2010. Household Cooking Gas Appliances. New York, NY: American Nationa Standards Institute.

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. 2008. Standard 160-2008, Criteria for Moisture Control Design Analysis in Buildings. Atlanta: ASHRAE

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

CPSC. 2001a. The Inside Story A Guide to Indoor Air Quality. U.S. Consumer Product Safety Commission, Washington D.C. http://www.cpsc.gov/CPSCPUB/PUBS/450.html, accessed Jan. 2012.

CPSC. 2001b. Carbon Monoxide Fact Sheet. U.S. Consumer Product Safety Commission, Washington D.C, 2001. http://www.cpsc.gov/CPSCPUB/PUBS/466.html, accessed Jan. 2012.

CU. 2005. Unvented Gas Fireplaces Can Go Almost Anywhere. But Are They Safe? CITY: Consumers Union, Consumer Reports March 2005, http://www.consumerreports.org/ cro/appliances/heating-cooling-and-air/fireplaces-gas/gas-fireplaces-306/index.htm, accessed Jan. 2012.

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

Francisco, P.W., J.R. Gordon, and B.Rose. 2010. Measured Concentrations of Combustion Gases from the Use of Unvented Gas Fireplaces. Indoor Air 20(5):370-379. Health Canada. 2011. Residential Indoor Air Quality Guidelines, http://www.hc-sc.gc.ca/ewhsemt/ air/in/res-in/index-eng.php, accessed Jan 2012.

Gergan, Pj., Weiss, K.B.(1992) "The Increasing Problem of Asthma in the United States". *American Review of Respiratory Disease*.. 146(4): 823-824.

Gold, D.R.(1992) "Indoor Air Pollution". Clinics in Chest Medicine.. 13(2):215-229.

HUD. 2005. Healthy Homes Issues: Carbon Monoxide. Washington DC: U.S. Department of Housing and Urban Development.

Hine, A et'al (1993); Indoor Air Quality and Control, PTR Parnetice hall, eaglrwood cliffs, New Jersey page 74-85

ICC. 2012. ICC International Fuel Gas Code. Washington DC: International Code Council, Inc.IOM. 2004. Damp Indoor Spaces and Health. Institute of Medicine, Committee on DampIndoor Spaces, Board on Health Promotion and Disease Prevention. Washington DC: National Academy of Sciences Press.

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

Knol, A. B., et al. 2009. Expert Elicitation on Ultrafine Particles: Likelihood of Health Effects and Causal Pathways. Particle and Fibre Toxicology 6:19.

Lipsett, M. (1992)."Oxides of Nitrogen and Sulfur." *Hazardous Materials Technology*; 000:964-69.

MMWR 1997. Use of unvented residential heating appliances – United States, 1988-199. MMWR 46(51):1221-1224; (http://www.cdc.gov/mmwr/preview/mmwrhtml/ 00050535.htm, accessed May, 2008).

Mudarri, D. andW.J. Fisk. 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 Jan. 2012.

Olopade S (2010) . Fighting Indoor Air pollution , Global Health, Lung, public health

Rogge W.F. et al. 1993. Sources of fine organic aerosol. 5. Natural gas home appliances. Environ. Sci. Technol. 27:2736-2744.

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

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 (1987. The Total Exposure Assessment Methodology (TEAM) Study; Project Summary.. EPA-600-56-87-002.

U.S. Environmental Protection Agency (1991), U.S. Public Health Service, National Environmental Health Association. "Introduction to Indoor Air Quality: A Self-Paced Learning Module". EPA-400-3-91-002..

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.

U.S. Environmental Protection Agency. "Building Air Quality: A Guide for Building Owners and Facility Managers". U.S. Government Printing Office. Washington, D.C. EPA-055-000-00390-4. December 1991.

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

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, China

APPENDIX I-QUESTIONNAIRE

DEPARTMENT OF BUILDING

FACULTY OF ENVIRONMENT DESIGN

AHMADU BELLO UNIVERSITY, ZAIRA

Dear respondent,

QUESTIONNAIRE ADMINISTERED FOR AN ASSESSMENT OF THE INFLUENCE OF COMBUSTION GENERATED POLLUTANTS ON THE INDOOR AIR QUALITY OF SELECTED LABORATORIES IN AHMADU BELLO UNIVERSITY ZARIA

This questionnaire is intended to be used in 'An Assessment Of The Influence Of Combustion Generated Pollutants On The Indoor Air Quality Of Selected Laboratories In Ahmadu Bello University Zaria'. It will be used for academic purposes only. You are requested to kindly study and complete the questionnaire as carefully as possible.

Thank you.

Section 1: Personal data

1) Sex?

a) Male ( )

b) Female ( )

2) Status?

a) Staff ( )

b) Student ( )

3) What age range do you fall into

a) Below 20yrs ( )

b) 21-30yrs ( )

c) 31-40yrs ( )

d) 41 and above ( )

Section 2: Laboratory Use Characteristics

4) Do you make use of the laboratory?

a) Yes

b) No

5) If 'No', have you ever being in a laboratory where combustion activity is taking place? if yes proceed to question 6

a) Yes ( )

b) No ( )

6) If No to question five above, proceed to section 3, .How often to you use the laboratory in a week?

a) Once a week ( )

b) Twice a week ( )

c) Daily including week days ( )

d) Daily including weekends ( )

7) How many hours per day do you spend in the laboratory

a) 0-2hrs ( )

b) 3-4hrs ( )

c) 5-6hrs ( )

d) 7-8hrs ( )

e) 9hrs and above ( )

8) Does you work entail combustion activities

a) Yes ( )

b) No ( )

9) What is the device used in generating the heat for the combustion activity

a) Candle ( )

b) Stoves ( )

c) Gas burners ( )

d) Hot plates ( )

10) Do you have a gas fume hood installed in the laboratory

a) Yes ( )

b) No ( )

11) Are the gas fume hoods functional?

a) Yes ( )

b) No ( )

12) Do you experience discomfort in the laboratory during the combustion activities?

a) Yes ( )

b) No ( )

13) During which kind of activity do you experience the discomfort more?

a) combustion process ( )

b) Filtration process ( )

c) Lab cleaning process ( )

d) Distillation ( )

14) Are there ventilation systems provided in the laboratory?

a) Yes ( )

b) No ( )

15) Is the ventilation during the combustion activities appropriate?

a) Yes ( )

b) No ( )

Section 3: Health Symptoms of Poor Indoor Air Quality

16) Do you have any allergies or other health problems that may account for any of the listed symptoms?

a) Yes ( )

b) No ( )

17) Rank the following as the major symptoms of discomfort due to combustion in the laboratories (1 to 7). (1 –strongly agree, 2 – agree, 3 –undeceive, 4- disagree, 5-Stongly disagree)

s/n	**Symptoms of poor indoor air quality due to combustion**	**1**	**2**	**3**	**4**	**5**
a.	Dryness and irritation of the eye, nose, throat and skin					
b.	Headache					
c.	fatigue					
d	Shortness of breath					
e	Hypersensitivity and allergies					
f	Sinus congestion					
g	Coughing and sneezing					

h	Dizziness					
i	Nausea					
j	Blurred vision					
k	Pains and discomfort					
l	Heart burn					
m	Sneezing and chest tightness					
n	Fainting					

18) On average, how long have combustion process taken, when you notice the symptoms?

a) Less than 1hour ( )

b) 2-4hrs ( )

c) Greater than 4hrs ( )

d) Greater than one day ( )

19) Have the pain or discomfort caused you to take times off the work

a) Yes ( )

b) No ( )

Section 4: HVAC and combustion related factors that are the causes of discomfort

20) Rank the following activities as a major cause of the discomfort in the laboratory (1 to 7). (1 – not a cause , 2- not a major cause , 3- barely a cause, 4- a cause, 5- always a cause)

s/n	Measure	1	2	3	4	5
a.	Combustion activities					
b.	Inadequate ventilation in the laboratories					
c.	None functional fume boxes					
d.	Unventilated combustion equipments					
E	Prolonged and reoccurring combustion activities					
F	Excess students carry combustion activities beyond the capacity of the number of students that the laboratory was built for					
G	Faulty bursen burners leading to the generation of more fumes					

H	Air too humid					
I	Too little air movement					

21) Do you think prompt attention should be paid to the indoor air quality in laboratories

a) Yes ( )

b) No ( )

22) If 'No' state what you think should be done to enhance combustion in the laboratory and yet not jeopardizing human health? If yes, proceed to the next section

……

……

Section 5: Remedial Approach to the Discomfort due to poor indoor Air Quality

23) Rank the following activities as a measure of improving the indoor air quality within the laboratory (1 to 4). (1 very Effective –, 2- Effective, 3- moderately Effective, 4- not Effective)

s/n	Measure	1	2	3	4
a.	Provision adequate Heating Ventilation and Air conditioning system (HVAC)				
b.	Introduction and maintenance of a functional fume boxes				
c.	Ensuring adequate air flow rate especially during combustion activity				
d.	The use of excellent combustion equipment that will reduce the rate of generation of CO				
E	Orientation of both staff and student on the danger in carryout combustion without adequate air flow				

Thank you for your co-operation

APPENDIX II- CHECKLIST

DEPARTMENT OF BUILDING
FACULTY OF ENVIRONMENT DESIGN
AHMADU BELLO UNIVERSITY, ZAIRA

A CHECKLIST ADOPTED FOR AN ASSESSMENT OF THE INFLUENCE OF COMBUSTION GENERATED POLLUTANTS ON THE INDOOR AIR QUALITY OF SELECTED LABORATORIES IN AHMADU BELLO UNIVERSITY ZARIA

INSPECTORS: ……		
LOCATION/ DEPARTMENT: ……. **DATE: ……..**		
(√) Satisfactory/Present/ ok (X) Unsatisfactory, requires attention/absent/ insufficient		
S/N	**GENERAL OBSERVATIONS (Walls, Ceiling and Floors)**	
1	Wall ceiling, work bench and window are free of mould	( )
2	Indoor plants free of mould and odor	( )
3	Flat surfaces dust free	( )
4	Thermostats in enclosed offices	( )
	DIFFUSERS	
5	Diffuser are unobstructed	( )
6	Diffuser condition(mould, dirt, duct)	( )
	AIR EXHAUST LOUVERS	
7	Louvers are unobstructed	( )
8	Louvers condition is clean	( )
	POLLUTANTS SOURCES (~3METER FROM WORK AREAS)	
9	Chemical storage/ handling area	( )
10	Position of bursen burners	( )
11	Number of burners per work table	( )
	CABON MONOXIDE SOURCES	
12	Bursen burners, and other heating appliances	( )
13	Gas fired heating system	( )
14	Free standing gas heaters	( )
15	Other heating devices	( )
	CIGAREETTE SMOKE	
16	Smoking policy in place enforced	( )
	VENTILLATION STSTEM (HVAC)	
17	Adequate outdoor air intake	( )
18	Air intake clear of pollution sources	( )
19	Cleanliness of ducts and plenum	( )
20	Ventilation shut-down (nightly/ weekends)	( )
	Intake vent blocked, rusted	

	Exhaust vent blocked, rusted or debris present	
21	Presence of air filter	( )
22	Air filter condition	( )
	HUMIDIFIERS	
23	Pans and wetting media are free of slime	( )
24	Duct are free from moulds	( )
25	Presence of fans	( )
26	Use of volatile chemical for humidifier	( )
	AIR CONDITIONING SYSTEMS	
27	Condensate trays free of slime	( )
28	Cooling coil free of slime	( )
	GENERAL MAINTERNANCE DESIGN	( )
29	Windows can be opened	( )
30	Alterations to ventilation system	( )
31	Number of occupants in area	( )
32	Usage/condition of carpeting	( )
33	Work are repainted	( )
34	Presence of odors	( )

APPENDIX III- EXPERIEMENT RECORD SHEET

Session Of The Experiment	TYEPE OF COMBUSTION POLLUTANTS	Lab Name …….									
		Measurement BEFORE COMBUSTION			Measurement DURING COMBUSTION			Measurement AFTER COMBUSTION			AVERAGE
		1ST POINT	2ND POINT	3RD POINT	1ST POINT	2ND POINT	3RD POINT	1ST POINT	2ND POINT	3RD POINT	
First Session Of The Experiment	O_2 (%)										
	CO(PPM)										
	NOx										
	SO_2										
	CO_2										
Second Session Of The Experiment	O_2 (%)										
	CO(PPM)										
	NOx										
	SO_2										
	CO_2										
Third Session Of The Experiment	O_2 (%)										
	CO(PPM)										
	NOx										
	SO_2										
	CO_2										

APPENDIX IV –PLATES OF RESEARCH AREA

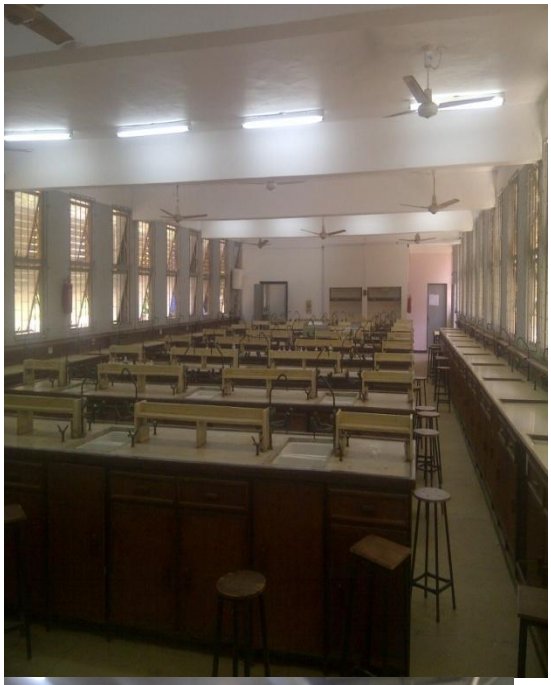


Fig 1: Chemistry Lab I

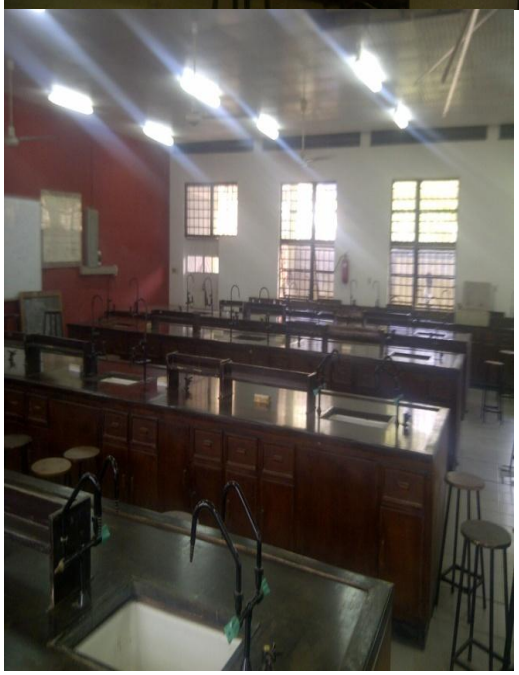


Fig 2: SBRS Lab II

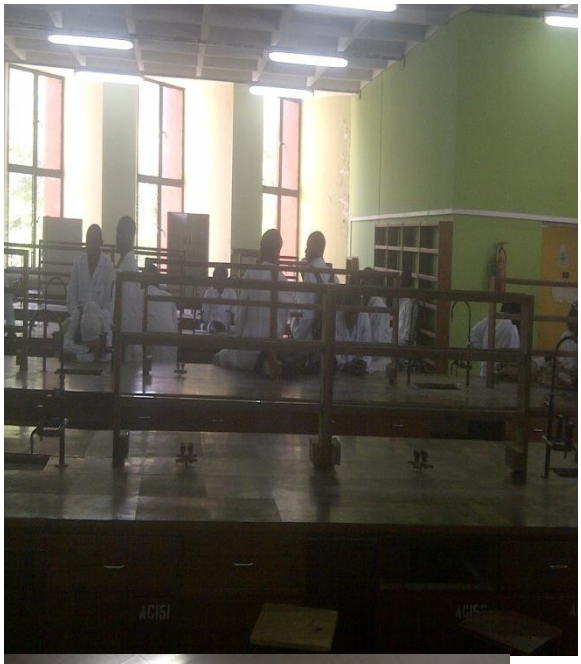


Fig 3: SBRS Lab III

Fig4: Chemistry Multi Purpose Lab

FIG 5: Physical Chemistry Laboratory

Fig 6: Masters Students Lab

Fig 7: Students Working In Group Practical

Fig 8: Lab Prepared Before

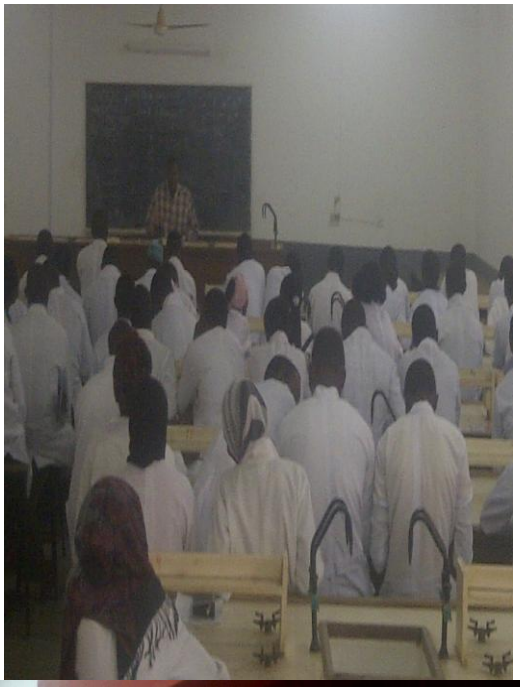


Fig 9 : Student Taking A Pre-Lab Class

Fig 10: A Fume Hood

Fig 11: A Water Bath Alternative Heater Calibrating

Fig: 12 IMR 1400C Gas Analyzer

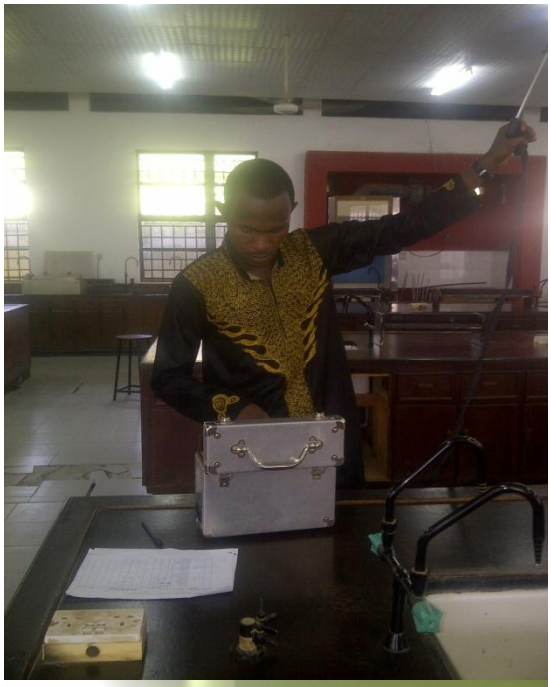


Fig13: taking readings before practical

fig 14: taking reading during practical

Fig 15: Taking Readings after a Concluded Practical

Fig16: Over-Crowded Student during Practical