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By

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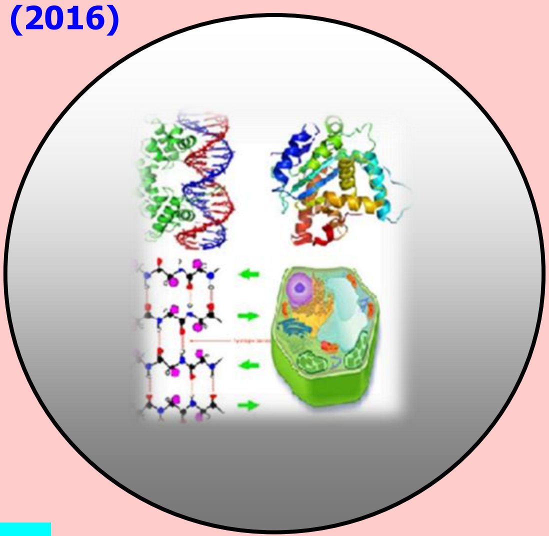

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RESEARCH PAPER

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Indoor Air Quality in an Undergraduate Chemistry Laboratory of a College in Lucknow

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ABSTRACT

The laboratories possess characteristic indoor air quality (IAQ) governed by the physical, chemical and biological properties of the indoor air which directly affects the comfort, health and performance of the students. The present study was undertaken to determine the concentration of NO_2, SO_2, TSPM and PM_{10} inside and outside the lab of the chemistry department in light of the safety limits for IAQ and AAQ. A survey was also conducted by a direct method on 130 students on the immediate health effects. The concentration levels in AAQ reached a high of 473µg/m^3 TSPM and 194µg/m^3 PM_{10} for 24 hours and 67µg/m^3 NO_2 and 18.7µg/m^3 SO_2 for 8 hours when the labs were functional indicating that the chemistry lab was responsible for the high values. The concentration levels in IAQ of NO_2 and SO_2 were alarmingly high as well, which were 27.3µg/m^3 and 9.2µg/m^3 respectively, for 8 hours. They formed white haze causing respiratory illness, irritation to eyes, throat, thirst and tiredness to the students. Remedial measures have been done like planting trees in the grounds outside as well as putting potted plants inside the labs and changing to clean green work practices to create comfortable, healthier environment for working.

Key words: IAQ, AAQ, TSPM, PM_{10}, NO_2, SO_2, chemistry lab and students.

INTRODUCTION

Rapid urbanization and industrial development of India in the last few decades has given rise to countless buildings viz- offices, educational institutions, shopping malls, hospitals, hotels, theatres etc. Each of these buildings possesses its own characteristic indoor air quality (IAQ) which is governed by the physical, chemical and biological properties of the indoor air i.e. the concentrations of pollutants and thermal conditions (heat/cold) of the air that circulates throughout closed space/ area, where people work, live and breathe.

Table 1. Sources of Pollutants in the Chemistry Laboratory.

Pollutant or Pollutant Class	Potential Sources
NO_2, SO_2, Combustion contaminants, O_3, CO	LPG, Bunsen burner, outdoor air, generators, and vehicular traffic.
Biological contaminants	Microorganisms (wet or damp materials, drainpipes, damp duct, or filters), exhausts, bird droppings, cockroaches, rodents, dust mites on furniture, pollens.
Volatile Organic Compounds (VOCs), Formaldehyde (HCHO)	Particle board, plywood, cabinetry, furniture, paints, varnishes, stains, solvents, adhesives, wood preservatives, waxes, lac, cleansers, dyes, plastics, traffic emissions.
Soil and Sewer gases (Ra, H_2S, CH_4, NH_3, CO_2)	Sewer drain leak, dry drain traps.
Pesticides	Insecticides, fungicides, disinfectants.
Particles and Fibres TSPM, PM_{10} & $PM_{2.5}$	Deterioration of materials, construction/renovation, chalk, dust, soil dust, cleaning activities, resuspension of particles due to student's movements, combustion sources (heaters and LPG)

Source: Slezáková *et.al*. (2012)

Table 2. Health effects of indoor air pollutants present in the chemistry lab.

Pollutant	Type	Effect
NOx	Immediate	Irritation to nose, eyes, skin and throat, Cough.
SOx	Immediate	Lung disorder and shortness of breath.
TSPM/ PM_{10}	Cumulative	Respiratory illness (upper and lower), COPD, asthma, lung cancer.
VOCs	Immediate	Liver, kidney disorders, irritation in eyes, nose and throat, skin rashes and respiratory disorders.
O_3	Immediate	Skin rashes, itching and burning in eyes, prone to pneumonia and respiratory disorders.
CO	Immediate	Headaches, shortness of breath, sudden death.
HCHO	Immediate	Irritation to skin, ENT (eyes, nose, and throat), headache, fatigue, vomiting.
Pesticide	Immediate	Skin allergy

Source: Slezáková *et.al.* (2012)

As more and more people spend more time indoors, IAQ directly affects their comfort, health and performance (Katiyar and Khare, 2008).

India is a tropical country where most of the educational institutions have buildings which are naturally ventilated with a significant impact of outdoor air on the IAQ (Chithra and Nagendra, 2012). Urban educational institutions which are located in close proximity to roads with heavy-traffic experience outdoor pollutants too (Goyal and Khare, 2011). The class rooms and laboratories in colleges and universities have very high population density where students and staff are exposed to the special microenvironments (Tugba *et. al.* 2015), and are vulnerable to the ill-effects of indoor air pollution.

The chemistry laboratories have intrinsically the potential for polluting the indoor air (Table -1) as well as the outdoor air.

Poor IAQ in the labs can increase the chances of short-term and long-term health problems of students, lab assistants, lab boys and teachers who are directly exposed to the chemicals by inhalation and dermal routes while working (Table 2). This occupational hazard of the chemistry lab reduces the productivity of teachers and students and consequently degrades the learning environment and comfort levels and discourages the students from studying chemistry.

The present study was undertaken to determine the concentration of NO_2, SO_2, TSPM and PM_{10} inside and outside the lab of the chemistry department in light of the safety limits for indoor air quality. Simultaneously, a survey was conducted to assess the immediate discomfitures of the students and staff while working in a chemistry laboratory at NSN (PG) College, Lucknow. This study will help us to establish a link between the work practices, laboratory housekeeping, ventilation and the building design which in turn can determine the general air quality and the occupational exposure. The outcome will facilitate effective measures to improve the IAQ of the chemistry laboratories which in turn will improve the AAQ and prevent serious health risks.

MATERIAL AND METHODS

Site description

Nari Shiksha Niketan (PG) College is located in a crowded commercial area on Mona Chandrawati Road, Kaiser Bagh, Lucknow-226001, Uttar Pradesh (Fig-1). The Kaiser Bagh Bus Station is only 190mts away from the Chemistry Department having a very heavy flow of traffic with about 1200 buses plying every day and footfall of approximately 24000 (Bus-time-table Kaiser Bagh, 2016). The department of chemistry is housed in the ground floor of a two storied naturally ventilated building (Fig-2). There is a volley ball court in front and an urban slum behind it. The department has two laboratories, one store, one staff room, one weighing room and an OTS (open to sky) with a dedicated area for the LPG cylinders**.**

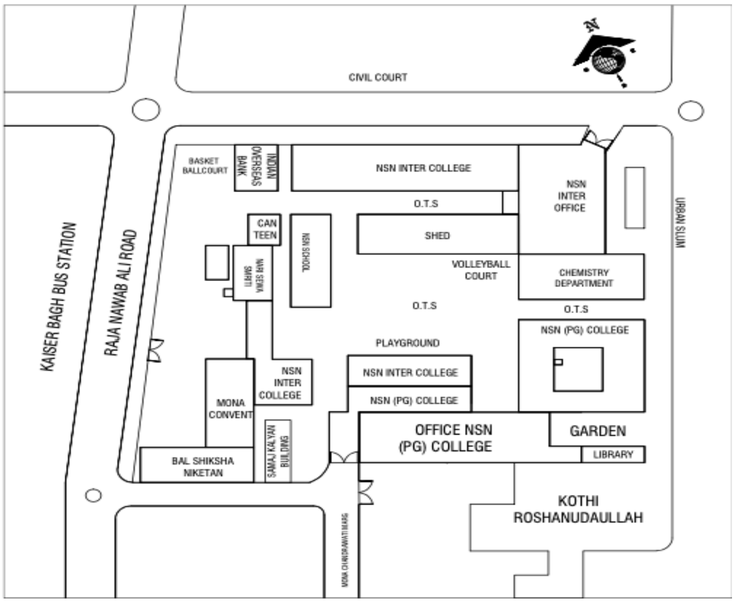

Figure 1. Building design of the NSNPG College.

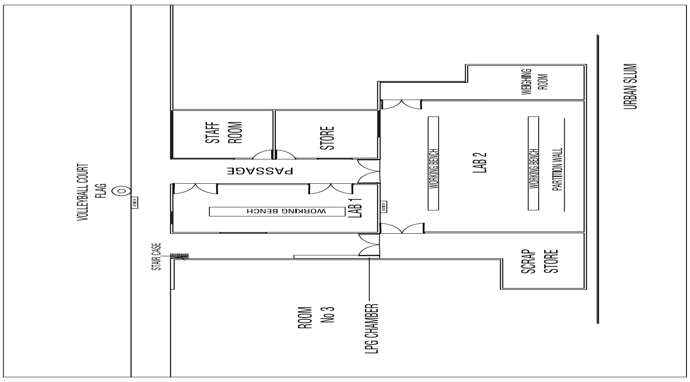

Figure 2. Building design of chemistry department.

Lab-1

The dimensions of lab-1 are 33'X17'X14' with two doors (opening in the passage), six windows (of which two windows are closed), six ventilators (one ventilator is closed) and is equipped with a Fume Chamber (1hp motor of 1400 RPM), two exhaust fans (900RPM), three fans.

Lab-2

The dimensions of lab-2 are 31'X 24'X14' with three doors(one opening in the OTS, second in the weighing room and third in the passage), one window, five ventilators and two exhaust fans(900RPM). The weighing room measures 24'X10'X10' has four windows and one ventilator.

Store

The dimensions of store are 12'X12'X14' with a door (opening in the passage) and three windows (two closed, one opening in the weighing room).

OTS

The dimensions of OTS are 36'X 9' with the H_2S plant (functional lab). The LPG cylinders are stored in a special room with dimensions of 6'X4'X7'.

Staff room of 16'X14'X12'dimensions with a door (opening in the passage), three windows, a fan and an exhaust fan of 1400RPM.

Sampling and Monitoring

(1)The indoor and outdoor concentrations of TSPM, PM_{10}, NO_2, SO_2 and the comfort variables i.e. temperature and RH (relative humidity) were monitored in the warm spring season of mid-February under the following conditions:

(i) when the labs were fully occupied (40 students and 3 employees) and functional during the BSc examinations and

(ii) the next day when the labs were not functional.

Indoor and outdoor air samples were taken (inside the lab and at the entrance) for NO_2 and SO_2(8 hours each) and 24 hours for PM_{10} respectively by the following methods(Fig-3):

Table 3. Sampling and Monitoring Methods.

Sampling	Description	Monitoring Method / Instrument
Pollutant / contaminants	TSPM, PM_{10}	Using High Volume (HV) Sampler in Ambient Air and low volume sampler in Indoor Air by the Cyclonic flow technique and the concentration was determined Gravimetrically
	SO_2	Improved West & Gaeke method, where SO_2 was estimated at 560nm using the spectrophotometer.
	NO_2	Modified Jacob & Hochheiser ($NaOH-NaAsO_2$) method and NO_2 was estimated at 540nm using the spectrophotometer
Ventilation parameters	Fume Chamber Exhaust fans Ceiling fans	1HP motor with1400 RPM Number: 4 of 900 RPM (Revolutions per minute) 6
Comfort parameters	Temperatures	Mercury thermometer
	Relative humidity	Humidity gauge, psychrometer
Occupancy	Number of students Staff	40 3

Source: National Ambient Air Quality Standards (CPCB)

i) Inside the Lab

ii) Entrance

Figure 3. Position of Monitors at chemistry department.

(2) A survey was conducted of the 130 BSc students and 3 staff members on the immediate effects while working in the chemistry lab due to its Indoor Air Quality. The data collection was performed by a direct method through a Google form questionnaire which was pre-tested, self-designed and close-ended comprising of questions related to immediate symptoms like irritation to eyes, nose, throat and skin on exposure to the laboratory's fumes. National Ambient Air Quality Standards, Central Pollution Control Board India and Indoor air quality Standards, World Health Organization have been used to evaluate the general micro–environment of the chemistry laboratories at NSN (PG) College, Lucknow.

RESULTS AND DISCUSSION

The indoor air pollutants in the Chemistry lab can be categorized in two distinct groups:
i) Pollutants causing chronic effects i.e., particulate matter (PM) and VOCs.
ii) Pollutants causing acute effects i.e. NOx, SOx, CO, trace elements like Hg, Pb, As etc.

Table 4. Monitoring results.

Pollutants	PM_{10} (µg/m^3)	TSPM	NO_2 (µg/m^3)	SO_2 (µg/m^3)	RH%	T ^{0}C
IAQ	µg/m^3 (24 h)		µg/m^3 annual mean	µg/m^3 (24 h		
Indoor Monitoring Standards WHO/NAAQS	50		40	20	-	-
Lab						
Day 1 Functional	7.13(24h)		24.3(8h) 27.3(8h)	6.1(8h) 9.2(8h)	85%	24.5
Day2- Non-functional	5.19(24h)		24.3(8h) 22.9(8h)	3.1(8h) 6.1(8)	93%	20.7
AAQ						
Outdoor Monitoring Standards WHO	100 µg/m^3 (24 h)		80 µg/m^3 (24 h)	80 µg/m^3 (24 h)		
Day1-Functional	194(24h)	473(24h)	46.8 (8h) 64.7 (8h)	18.7 (8h) 18.4. (8h)	83%	24.8
Day2- Non-functional	123(24h)	460(24h)	46.5 (8h) 44.3 (8h)	11.7 (8h) 5.9 (8h)	87%	20.4

Particulate Matter

Particulate Matter is a mixture of solid particles and liquid droplets present in the air which is identified as a Group-1 carcinogen and a major indoor air pollutant. It is emitted from various sources like chalk dust, soil dust, new furniture, cleaning activities, resuspension of particles due to the movement of occupants, combustion sources such as heaters, gas and wood stoves, outdoor traffic and industrial emissions. These atmospheric PM particles have morphological, chemical, physical and thermodynamic properties and vary in size from a few nano-meters to one hundred micro-meters. Particles are generally classified as 'coarse' and 'fine' particles according to the aerodynamic diameter (CPCB, Final Report-AQI,2014)
(1) Total Suspended Particulate Matter (TSPM): comprises all airborne particles up to 100µm.
(2) PM_{10}: Particles with an aerodynamic diameter < 10µm with a 50% efficiency cut-off.
(3) $PM_{2.5}$: Particles with an aerodynamic diameter < 2.5µm particles by almost 100%.

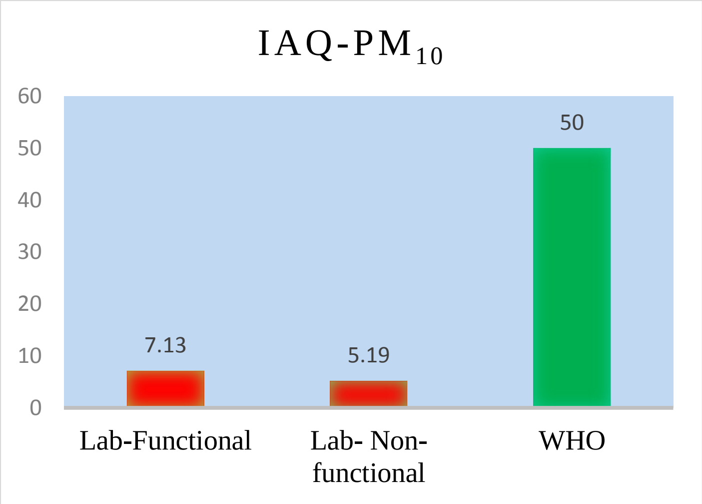

Figure 4. Concentration of PM_{10} inside the chemistry lab compared with WHO guidelines.

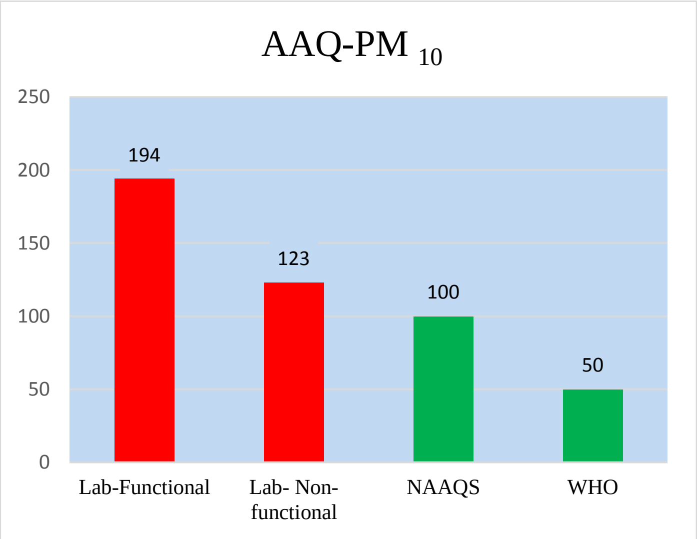

Figure 5. Concentration of PM_{10} outside the chemistry lab compared with NAAQS and WHO guidelines.

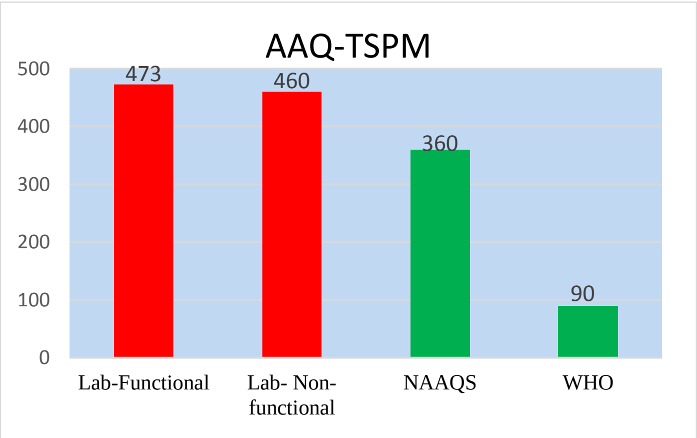

Figure 6. Concentration of TSPM outside the chemistry lab compared with NAAQS and WHO guidelines.

The concentration of PM_{10} inside the lab was 7.13µg/m^3 and 5.19 µg/m^3 which were within the permissible limit (Fig-4), but it crossed the permissible limit outside with the value being 194µg/m^3, while the lab was functional and decreased to 124µg/m^3 when the labs were non-functional (Fig-5). The high values of PM_{10} outside even when the lab was non-functional, was due to the close proximity of the Bus station(190m) with very heavy traffic and the movement of girls in the volley ball court which increased when the labs were functional. Similarly the Total Solid Particulate Matter(TSPM) in the ambient air was 473µg/m^3 and 460µg/m^3 when the labs were functional and non-functional, and were much above the permissible limit of 360µg/m^3 declared by revised NAAQS, (CPCB 2009-10)(Fig-6). Exposure to particulate matter may lead to detrimental effects on respiratory system, such as inflammation, asthma and cardiovascular system such as variability in the heart rate. The level of toxicity depends on the trace element and organic substance content which may be incorporated during the formation of particles (Gilmaur *et al* 1996).

Gaseous Pollutants

The major gaseous pollutants found in the chemistry laboratory are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ammonia (NH_3), sulphur dioxide (SO_2), ozone (O_3), CO_2, CH_4, CFC and VOCs.

Nitrogen dioxide (NO_2)

NO_2 is one of the most important and frequently encountered indoor air pollutants in the lab as a combustion product from the Bunsen burners. The other sources of NO_2 are the chemistry exercises and construction materials. As the concentration of NO_2 increases in the atmosphere it absorbs visible solar radiation causing impaired visibility. Hence, ventilation plays a major role because it may act as a highway for their transport from indoors to outdoors and vice-versa.

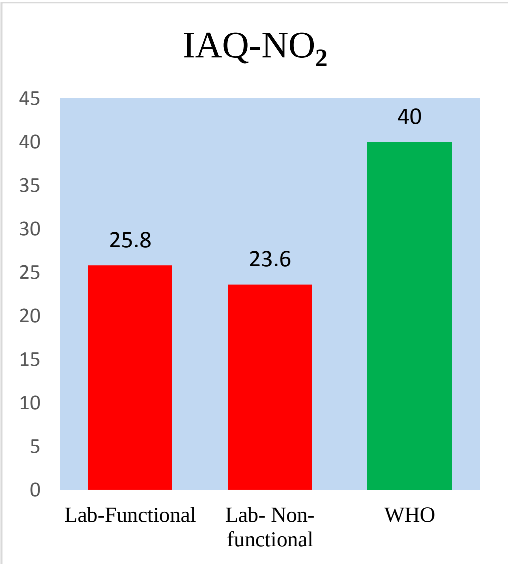

Figure 7. Concentration of NO_2 inside the chemistry lab compared with WHO guidelines.

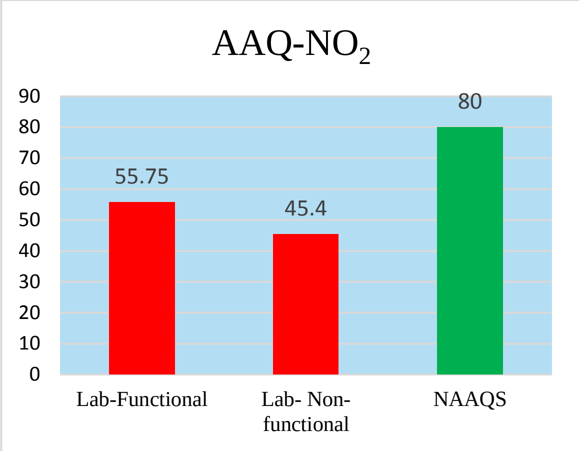

Figure 8. Concentration of NO_2 outside the chemistry lab compared with NAAQS guidelines.

On the day of examination, when the labs were fully occupied and functional, the concentration of NO_2 in the initial 8 hours was 24.3 μg/m^3 which later increased to 27.3μg/m^3 at night (Fig-7). The concentration level decreased in the initial 8 hours on the next day to 24.3μg/m^3 which further decreased to 22.9μg/m^3, when the labs were non-functional and unoccupied. This concentration of NO_2 was within the permissible limit as the chemistry labs are very well ventilated with 7 windows, four exhausts and a fume chamber which could clear the indoor air within 8 hours. The concentration of NO_2 outside the lab was initially 46.8μg/m^3 which increased to 64.7 μg/m^3 on the day of the examination (functional and fully occupied) whereas on the next day(non-functional and unoccupied), it decreased to 46.5μg/m^3 which further decreased to 44.3μg/m^3(Fig-8). This increase in the concentration of NO_2 inside and outside the lab when functional clearly indicates that the work in the lab was responsible for its increase. Exposure to NO_2 above 5ppm can cause lower respiratory diseases by damaging the lungs especially in asthmatics. Short-term associations of NO_2 with PM_{10} show cardiovascular and respiratory disorders (Jarvis, 2010).

Sulphur dioxide (SO_2)

The main source of SO_2 outdoors is power generation, motor vehicles and inside the lab is combustion of LPG and the experimental work. Sulphur dioxide (SO_2) is a colourless gas at room temperature and a colourless liquid under pressure. It is a non-flammable, highly soluble gas with an irritating and pungent odour with an acidic taste. It forms aerosols in the atmosphere and dissolves easily in water to form sulphuric acid.

The level of SO_2 inside the lab when functional and fully occupied was 9.2μg/m^3 in the initial 8 hours with a haze in the lab as SO_2 and other sulphur oxides react with air to form aerosols which reduced the visibility. The levels decreased to 6.1μg/m^3 at night which further decreased in next 16 hours to 3.1μg/m^3 when the lab was non-functional (Fig-9). The concentration of SO_2 in the AAQ outside the lab was 18.7μg/m^3 when it was functional and fully occupied. The levels decreased the very next day to 11.7μg/m^3 and later to 5.97μg/m^3 when the lab was non-functional indicating that working in the labs only was responsible for the high levels of SO_2 (Fig-10). Although the SO_2 levels both indoors as well as outdoors was within the prescribed permissible limits but it was enough to cause a haze and irritation in the eyes.

Occupational exposure to SO_2 limit (OEL) is 2ppm and can occur via inhalation, skin and/or eye contact. In the chemistry department the exposure to SO_2 is primarily due to the qualitative and gravimetric analysis and the H_2S plant stationed in the OTS. Symptoms of exposure to SO_2 are irritation of the eyes, nose and throat; rhinorrhea (discharge of thin mucus), choking, cough, reflex broncho-constriction, higher pulse rate, nausea and vomiting. Studies indicate that people with asthma experience changes in pulmonary function and respiratory symptoms after short exposure of 10 minutes only (Annesi-Maesano *et al,* 2013).

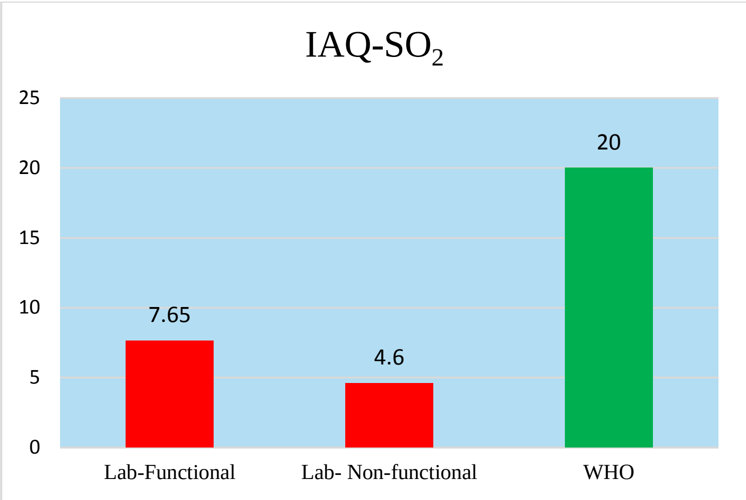

Figure 9. Concentration of SO_2 inside the chemistry lab compared with WHO guidelines.

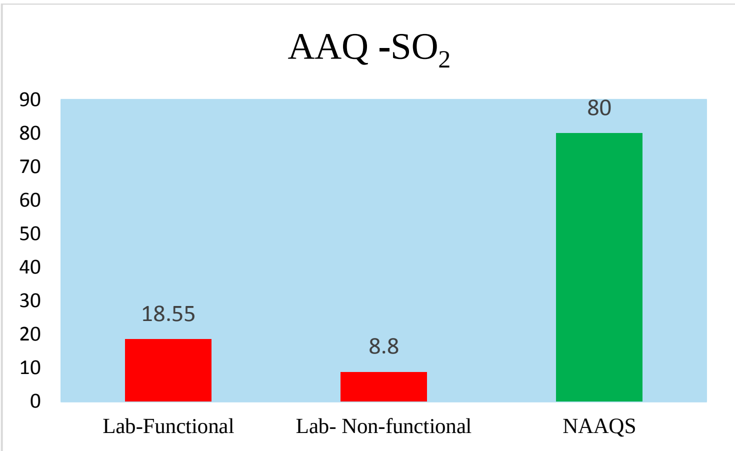

Figure 10. Concentration of SO_2 outside the chemistry lab compared with NAAQS guidelines.

Indoor Environmental Comfort Survey

The results of the questionnaire showed that 54.6% girls found the chemistry lab emitted an unpleasant odour. While working in the labs 19.1% girls felt nauseated, 20.6% had breathing difficulty, 50.4% had irritation in the eyes, 32.8% had experienced irritation in the throat while 20% had coughing, 37.4% had immediate headache or dizziness, 60.3% felt thirsty, 32.8% had sweating with muscle pain and 28.9% had burnt themselves or had an accident at-least once, twice or thrice.

As a consequence of working 44.6% girls always get tired, 17.6% get upset stomach, 47.3% have itching and rashes on the skin, 9.9% suffer from fever. All these immediate discomfitures generate phobia to 14.6% girls from the chemistry lab.

Along with IAQ, indoor environmental comfort is the second component of indoor environmental quality. Indoor environmental comfort consists of thermal comfort, noise, lighting, vibration and odours, all of which may affect the wellbeing and performance of the occupants. In an environment with lack of comfort, occupants may lose their concentration and may need to make an extra effort to work. The temperature on the day of the examination was 24.5^0C, the relative humidity was 85% inside the lab and the air change was done by the 4 exhaust fans of 900RPM rendering it thermally comfortable for working. The results of the survey clearly indicate that nearly half of the students who had opted for chemistry were not very comfortable while working in the labs. This discomfiture was due to the experiments or work practice of the labs and deters a large number of students from studying chemistry further.

Remedial Measures at Nari Shiksha Niketan (PG) College Lucknow

To provide and maintain healthy and comfortable working environment free of pollution at NSN labs the following remedies have been done:

- To expel the irritating fumes and odour of the concentrated acids; H_2SO_4, HNO_3, HCl, NH_4OH, Br_2 water, VOCs like Ethanol, CCl_4, CCl_3, Benzoyl Chloride, Picric acid etc are stored in fume the chamber fitted with an exhaust fan of 1400RPM.
- Work practice or chemistry has been altered by introducing semi-micro analysis in place of macro-analysis.
- Phyto-remediation: Keeping potted plants inside the lab to absorb the gases contaminating the IAQ.

i) Spider Plant for the absorption of CO
Areca Palm for the absorption of VOC-
Figure 11:

ii) Money plant, Common Fern and
Chinese evergreen for the absorption of VOC's-
Figure 12:

iii)Bougainvillea for the absorption of SO_2, NO_2-
Figure 13:

iv) Sadabahar for the absorption of SO_2, NO_2 and VOC-

Figure 14:

v) Planting trees outside the lab:

There are already 20 angiosperms like Neem, Guava, Jamun, Mango, Gulmohar, Gulacheen, Manokamini, Kaner etc. around the volleyball court (Fig-15). More trees like Hibiscus, Anar, Peepal, Bougainvillea have been planted in the ground and foliage have been planted in the old sinks near the windows, outside the lab to purify the air (Fig-16).

Figure 15. Volleyball court.

Figure 16. Plants outside the lab.

CONCLUSIONS

There is an urgent need to improve the quality of indoor air in the educational labs, since the air pollutants are usually higher than the values of IAQ set by the WHO. India does not have its own IAQ standards and guidelines for maintaining acceptable IAQ and there is a significant data-gap regarding the baseline IAQ for various buildings. Meeting the challenges that are posed by indoor air pollution will take some time. Meanwhile we must manage our indoor environments using the best available scientific advice by a systematic approach meant for assessment of indoor air quality and its possible consequences on occupants. It should be mandatory for educational institutions to continuously monitor and have clean green laboratory practices so as not to expose students to hazardous conditions.

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