International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 05 | May 2019 www.irjet.net p-ISSN: 2395-0072

Architectural Enhancement of Indoor Air Quality and Comfortability Level

Isabela Wilfred Mtani

Research Fellow, Institute of Human Settlement Studies, Ardhi University, P.O Box 35176, Dar Es Salaam, Tanzania.

Abstract

The indoor air quality of a building is a major factor that can affect the health and comfortability of its occupants. This study aimed at establishing whether there is indoor air quality problem in 5 residential apartments located in Upanga Area, Kinondoni Dar Es Salaam, Tanzania. Methodology for the assessment of the air quality of these apartments involved interview with residents, visual inspection, and measurements of indoor and outdoor conditions such as wind speed, humidity, particulates concentrations as well as post combustion products. Modeling of air flow was employed to study air flow pattern in one apartment as the apartment are similar in terms of design, size and occupancy level. The results highlight that, the apartment's location and orientation, internal spaces layout as well as the size and type of openings permit inadequate natural ventilation. Levels of relative humidity were found to be higher than recommended for human comfort. Particulate matters were also high, although their concentration was found to be below ASHRAE limits. Airflow pattern was mainly dominated with vortices, which inhibits fresh air exchange in the apartment. However, emission concentrations of CO, SO_2, NOx and HC gases were found to be within recommended thresholds. In general, findings suggest poorly designed building for efficient natural. Recommendations are architects to design based on climatic condition of the site locality by eliminate vortices and enhance efficient natural ventilation. Government shall put in place building codes for the design of living spaces in hot climate and establish guidelines for sustainable energy efficiency design.

Key Words: **Indoor air quality, Natural ventilation, Residential apartment, Comfort level, Health and safety.**

1.INTRODUCTION

The indoor air quality of a building is a major factor that can affect the health of its occupants. Growing attention is being paid to indoor air quality as one of the main health and well-being factors ([1] [2]). Human health is foremost when it comes to assessing the overall comfort of the environment [3]. Indoor air quality (IAQ) is an important issue that has both short term and long-term impacts on the health of occupants [4]. In most cases, poor indoor air quality is associated with insufficient fresh air as a result of poor air circulation in the respective area. Poor air circulation is normally caused by insufficient and/or incorrectly positioned window openings that hinder effective natural ventilation in a building. This may lead to compromised air quality due to aging of air. This has a direct effect on the comfort, health and productivity of the occupants [5]. On the health side, Buildings may cause illness to their occupants, producing symptoms e.g. nose irritation, throat, eyes, and skin, as well as shortness of breath, nausea, dizziness, and fatigue. These symptoms are commonly referred to as the Sick Building Syndrome (SBS) [2]. The common (SBS) related to Indoor air quality (IAQ) are inconspicuous and can lead to major health problems in the long term. Likewise, [6] linked asthma-related issues to IAQ. Furthermore, [7] and [8] recognized uncomfortable temperature and humidity, chemical and biological pollution, physical condition, and psychosocial status as some of the root causes of SBS.

Natural ventilation in tropical climates is intrinsic as it helps minimize energy utilization by limiting the loss of cool air and infiltration of warm air. Further Author [8] highlighted an increasing in the level of natural ventilation in non-industrial environments, improve the IAQ and minimize the concentration of air pollutants. Pollutants may come from both building material and occupants [9]. The rate at which natural ventilation is supplied should be proportional to the pollutants within the building [3], which usually vary contingent to the load and number of occupants. Natural ventilation can be enhanced by design solutions that promote cross ventilation and stack effect. If these techniques are not employed, this may jeopardize the indoor air quality and result into uncomfortable spaces. Thus, the building desires to have a proper mechanism for assessing the indoor pollutants, which will eventually enable the designer to control the ingress of natural ventilation into the building accordingly. In practice two common methods are employed to control the IAQ in a building by dilution and by source control [2]. The first one is to improve the IAQ by increasing the amount of the natural ventilation, which in turn minimises air pollutant [10] The second is by reducing the source of pollution within and outside the building in order to minimize the ingress of pollutants in the indoor air ([3], [2]). Nowadays, practitioner's supports dilution approach, believing that it is the better option to improvement the IAQ.

IAQ problems are more common in the buildings with insufficient ventilation [2]. Less or inadequate ventilation can create persistent odor, visible condensation, stagnant air, concentration of miscellaneous building pollutants (fragrances, cosmetics, cleaning agents) and off gassing from paints, plastics, fire retardants and synthetic building materials. Insufficient airflow in high humid indoor environments can create a conducive environment for mold growth and dust mite invasion. These conditions may lead to SBS include irritation of the eyes, nose, and throat, headache, cough, wheezing, cognitive disturbances, depression, light sensitivity, gastrointestinal distress and other flu like symptoms ([11]; [12]; [13]). Moreover, poor ventilation may alarmingly increase concentration of emissions such as carbon dioxide (CO_2), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NOx), hydrocarbon carbons (HC) and particulates that originates from the kitchen.

The main purpose of buildings is to create indoors more suitable for persons and processes than outdoors [12]. Since human being spends substantial time indoor, the choice of proper finishing materials for indoor spaces is intrinsic to enhance building performance as far as the IAQ is concerned hence their choice requires special consideration. Variety building materials are the major source of indoor VOCs (Volatile Organic Compounds) ([1], [2]). It is now clearly known with evidence that indoor VOCs exposure; the type of finishing building materials can affect absorption and movement. The re-emission of adsorbed VOCs by the building materials can dramatically increase VOC concentrations in the indoor environment for months or years after a source event ([14]; [15]). Choice of material can also assist in eliminating odor and harmful pollutants, increase thermal performance, and reduce indoor pollution. Architects and designers can select materials that do not produce irritating odour or VOCs, [3].

Building design involves abidance to country regulations, client's requirements consideration, knowledge of local environment and information on building materials. Others are cost and quality of the finished product. All these are necessary to create a healthy building. A healthy building is one that adversely affects neither the health of its occupants nor the larger environment.

Tanzania has different bodies that ensure health and safety of its citizens. On one hand, he has the occupational Safety and Health Authority (OSHA) whose work is to improve safety and security of workers in work places mainly industries and building sites by conducting health and safety audit. On the other hand, National Environmental Management Council (NEMC) [16] and fire brigade supervise environmental management issues of the new construction project and ensure abidance to fire regulations respectively. NEMC tool is environmental Management Act No. 20 of 2004, which provides for a legal and institutional framework for sustainable management of the environment [16]. Tanzania lacks building codes, which are necessary in supervising construction of building with quality indoor air. Consequently, clients and professionals are not obliged to come out with proper design solution with appropriate ventilation strategies to achieve required characteristic of healthy building.

1.1 Research objective

The main objective of the study was to assess the quality of air in relation to building design and materials in IST staff apartments. Specifically, by finding out the existing means of ventilation, determine the air quality and air flow pattern in the apartments and recommending appropriate measures. The paper provides scientific data on this assessment and discusses the findings in relation to the building design, orientation, and elements (openings) in in relation to IAQ in these apartments at IST's Upanga campus in Dar Es Salaam, Tanzania.

2. METHODOLOGY

2.1 Interview with residents of the apartment

The team interviewed the tenants, to get their perspective and living experience on health and safety of the apartment in relation to the indoor air quality.

2.2 Visual inspection of the apartment

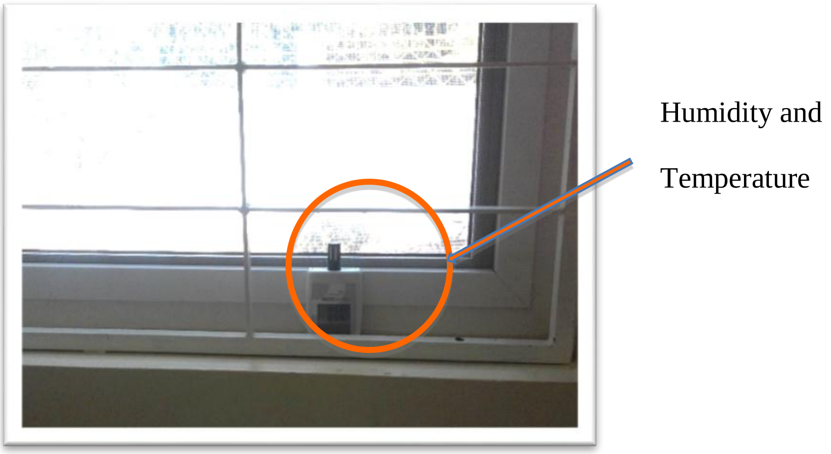
A comprehensive visual inspection of the apartment was done to see how ventilation works in the spaces, check available window openings and room heights.

2.3 Analytical measurements

Measurement of ambient air humidity and temperature, wind speed and particle impurities were taken. Prior to installation of measurement devices, residents were asked to state where they felt more uncomfortable while in the apartment. After identifying the experimental setup location, the measuring devices were located as shown in figure 1.

(a) Wind speed measurement

(b) Emission measurement



(c) Relative humidity and Temperature measurement (outdoor setup)

Fig -1: **(a, b & c):** Experimental setup for humidity and temperature, particulates, and emissions measurements.

2.3.1 Humidity and temperature measurements

The humidity and temperature outdoor and indoor were measured using Hanwell HL4106 Temperature and Humidity Data Logger. This device measures both temperature and humidity of the ambient air. The readings were taken at an interval of 5 minutes for 3 days. According to the manufacturer's specifications, the accuracy of the device is ± 3 %.

2.3.2 Particulate measurements

Particulates were measured continuously using DUSTRACK 8530. This device measures aerosol concentrations corresponding to PM1, PM2.5, respirable, PM10 or size fractions up to 400 mg/m3. Air sample was drawn in to the sensing chamber in a continuous stream using a diaphragm pump and the voltage across the photo detector was measured. The measured voltage corresponded to the mass concentration (µg/m3) of the aerosol. These values were recorded at an interval of 5 minute and stored in a data logger. According to the manufacturer, the accuracy of the device is ± 5 %.

2.3.3 Wind speed

The wind speed was measured using hand held Anemometer. Measurements were taken for 3 days to establish typical wind speed for modeling purposes. According to the manufacturer's specifications, the accuracy of the anemometer is ± 5 %.

2.3.4 Emissions measurements

Concentrations of CO, SO_2, NOx and HC were measured using Testo 350 Portable Emission Analyser. Measurements of other gases were taken three times and the average was reported on daily basis.

2.3.5 Modelling air flow in the apartment

Ventilation performance in the apartment was determined by computational fluid dynamics technique. This approach was aimed at studying airflow patterns to identify areas with hot spots. Boundary conditions considered were air velocity and pressure. The former was measured as described in Section 2.1.3 while the latter was set to 0 as the rooms were at atmospheric pressure. Moreover, wind speed was set at 0.5 m/s, 1.5 m/s and 3 m/s to represent typical values in Dar Es Salaam. The computational domain illustrating boundaries considered in this study is shown in figure 2.

2.4 Data quality assurance and quality control

The quality of data measured by equipment was based on the accuracy of the particular device as per manufacturer specifications. Moreover, calibration of DUSTRACK 8530 and gas analyser were carried out on daily basis. Data sampling was through programmed data loggers to minimize human errors.

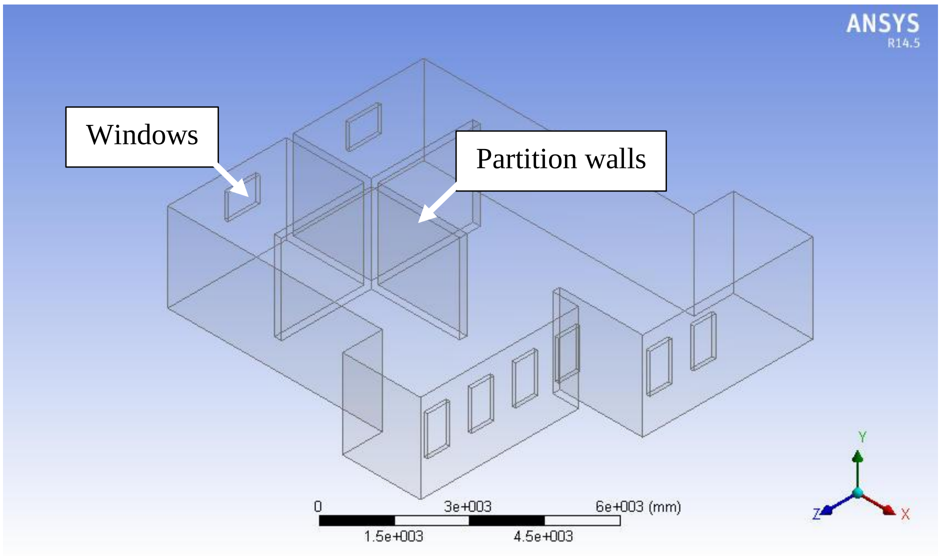


Fig-2.: Computational domain representing ground flow layout of the study area

2.5 Limitations

The use of air-conditioning by the residents in the spaces upstairs interfered with measurements taken from those spaces therefore measurements of air quality were taken on the ground floor and considered to be representative of the whole apartment. Parameters under considerations were particulate, relative humidity and temperature, wind speed, and gaseous emissions (CO, NOx, SO_2 and HC). Influence of other plants and other sources of pollutants of interest on the ambient air quality were not considered.

3. RESULTS AND DISCUSSION

3.1 Interview with occupants/ tenants

A brief interview with occupants, currently living in these apartments revealed the following:

- That most of them lived in the apartments for about 1.5 months.
- Throughout few of them experienced discomfort associated with asthma even though they never been asthmatic before.
- A few times that they slept in different places things were normal (no asthma)
- The doctor who treated these tenants has had three similar complaints from tenants who stayed in the same apartments previously.
- Tenants living in adjacent apartments have not complained of any such problems.

3.2 Visual analysis of the apartment.

3.2.1 Orientation and site layout.

An open area in front of the apartments has enough soft landscape to convert warm air to cool air. This is has the advantage of helping cool the adjacent rooms when wind blows into the rooms through the soft landscape. However, the position of apartment with asthmatic problem (in the middle of a double bank apartment block) and the building orientation hinder the maximum capturing of natural air into the building. Apartments are oriented southeast northwest, which is a favorable orientation toward wind direction, and one that deflects the dominant orientation of the sun in East-West (Fig. 3). However, it is a disadvantage that stronger winds for longer period of the year are blowing towards the side of the apartments with minimum openings. At the same time the double bank layout does not allow any air movement to affect the other side of the apartment. It would greatly help if the living, dining and kitchen spaces were designed as an open plan environment to allow free air movement from the back to the front of the ground floor. This strategy is in line with the recommendations by (Yousef Al horr, et al, 2016) that to increase daylight and natural ventilation green buildings often feature very high percentage of open. Moreover, the low lying level of the building makes it vulnerable to flooding hence promoting an increase in moisture contents in block walls. High moisture content and inadequate ventilation to replace warm air together create a conducive environment for bio-colonization (mold and dust mite).

3.2.2 Window type, layout and size

The design did not consider window position for cross ventilation, which is very important in the tropical climate. Window openings in opposite directions or perpendicular to each other maximize ventilation. This approach was not considered during design and construction of the house. Figure 4 and 5 indicate that the indoor air exchange is minimal and air circulation is limited to immediate spaces after the window. Window positioning provides no allowance for air to flow further from the window creating discomfort in shaded area. Green lines presents the ventilated areas when the doors are open and blue lines represent air flow through windows.

The apartments were designed to have PVC casement windows (W1) and PVC sliding windows (W2) as shown in Figure 4 and Figure 5. Allowance for natural ventilation provided by Breezeway technical bulletin 2012 for opening casement window is 90% while for sliding window is 50% as confirmed by [17]. The ventilation opening of a window is the openable size of the window and not the overall window size

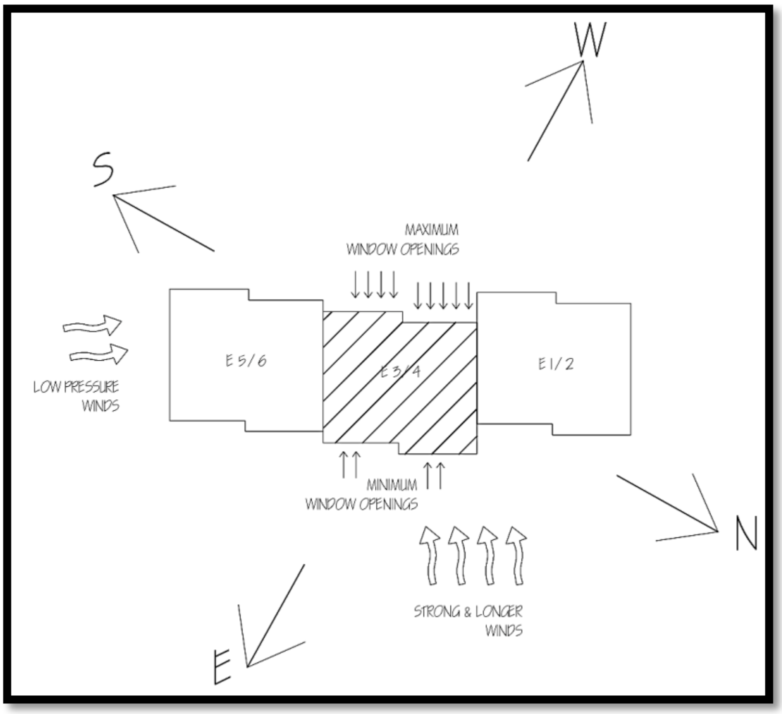


Fig-3: Building Orientation to minimize sun radiation and capture natural wind

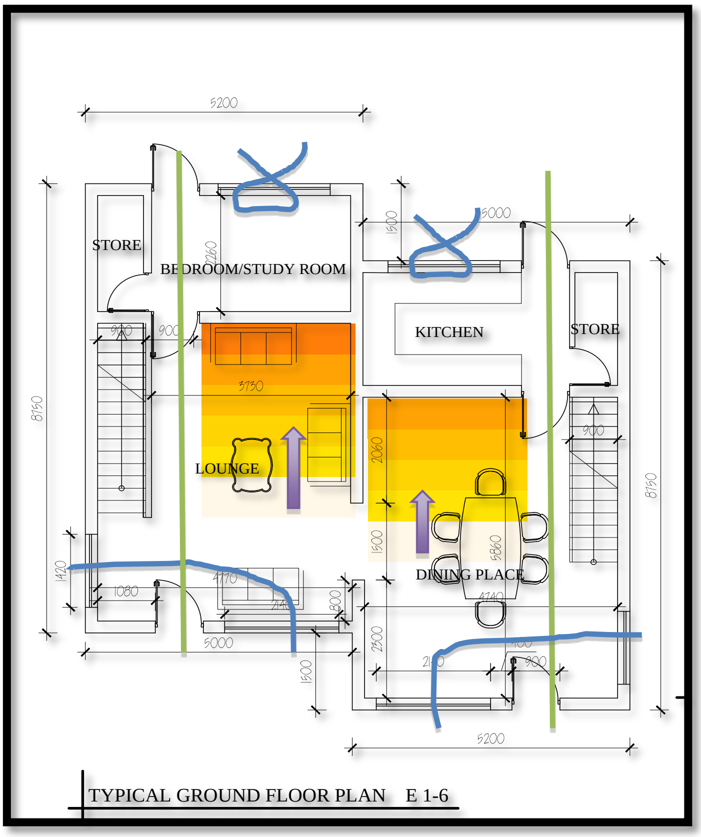


Fig-4: Air movement through windows and doors in Ground floor.

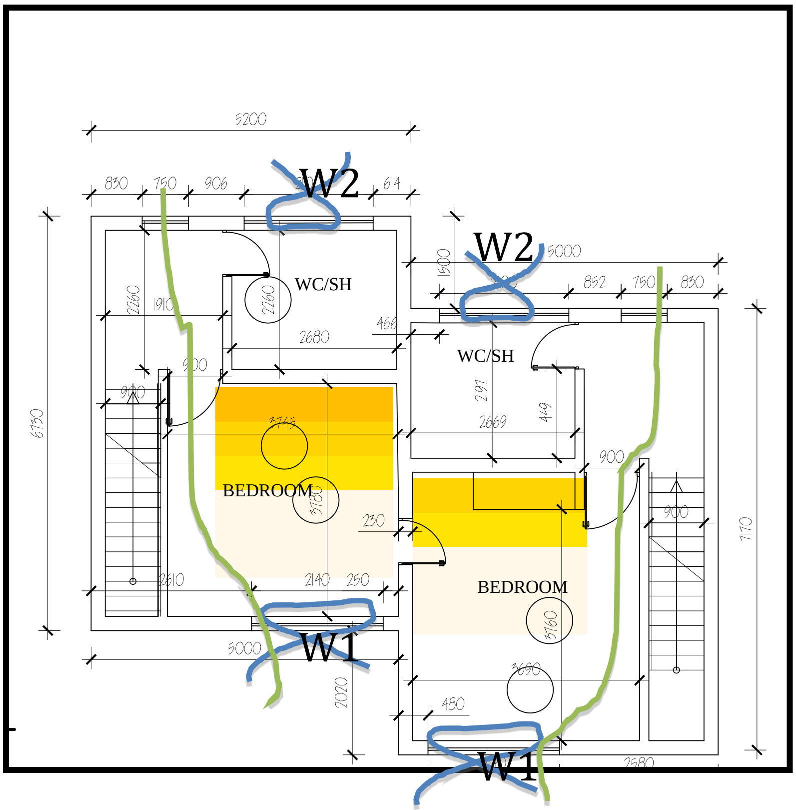


Fig- 5: Air movement through windows and doors in upper floor.

The PVC window type provided is not fully opened. Some shutters/sashes (about one third) have sealed glass reducing the capacity of the window to capture 90% natural ventilation. Window type has a massive impact on the amount of ventilation that a window will provide for cooling and indoor air quality[1]. Table 1 provides window types, sizes and ventilation area of the window.

Table -1: Window types, size and ventilation area.

Window Type	Window System	Window Size (h x w)	Total Window Area (TWA)	Ventilation Area (VA)	VA (% TWA)
Casement	W1	1.2m x 2.14m	2.57m^2	1.71m^2	67
Sliding	W2	1.2m x 2.1m	2.52m^2	1.26m^2	50

3.2.3 Roof type

This roof type and shape has a low attic volume (about 1 fold of wall area) hence cannot ward off sun radiation (reduce indoor insulation.

3.2.4 Room height

The room height (floor to ceiling) is found to be 2.5m, which is below the recommended room height in the tropical climate as referred to a study by [18]. This height tends to increase indoor temperature because of the limited volume of air in the room. Furthermore, low room height keeps the rising hot air too low almost within the human height hence creates uncomfortable living zones.

---

[1] *Breezeway technical bulletin, 09.08.2012 on Comparative Ventilation Openings of Various Window Types*

3.3 Analytical measurements

3.3.1 Humidity and temperature

Figure 6 presents the humidity and temperature profile of the indoor and outdoor air in apartments. The data acquisition equipment was set in the living room while the dehumidifier was off and all windows were opened. Similarly, the equipment was set at same position but the dehumidifier was in operation. The last day, the equipment was set to capture outdoor humidity and temperature for comparison purposes. It can be seen from the figure that the outdoor humidity was high at night compared to daytime. The maximum and minimum relative humidity was found to be 80.9% and 63.2% with corresponding temperatures of 32.7^{o}C and 29^{o}C respectively. The average values were found to be 75.6 % and 30.3^{o}C. On the other hand, the maximum and minimum relative humidity for indoor air was found to be 74.9% and 67.8% with corresponding temperatures of 32.3^{o}C and 30.5^{o}C respectively. The average values were found to be 72.7% and 31.1^{o}C. Moreover, the effect of dehumidifier managed to reduce the humidity to below 60 % for a period less than 30 minutes while most of the time was above 70%.

These results show that, the level of humidity as well as temperature are higher than the human comfort condition which recommends relative humidity of 56% and temperature of 24^{o}C. Another observation shows that, dehumidification without cooling elevates temperature as revealed by peaks on 10-11/12/2015 while the dehumidifier was operating. Findings from this study suggest that, dehumidification needs to be associated with cooling, thus, air conditioning could be an appropriate solution.

3.3.2 Particulate concentration

Table 2 shows the concentration of particulates in the ambient air in apartments. A total of 9 experiments, which spanned over 55 hours within a period of three days, were conducted. The maximum-recorded particulate concentration was 2.78 mg/m3. Lowest concentration observed was 0.13 mg/m3 in the evening. The Time Weighted Average (TWA) recorded was 0.71 mg/m3. Continuous recorded results of the experiment are attached as graphs in the appendices of this report. Generally the particulate concentration was found to be below the risk value of 10 mg/m3 (TWA) as recommended by the ASHRAE (or American Society of Heating, Refrigerating, and Air-Conditioning Engineers)

Table-2: Summary of Particulate Measurement Experiment results

Experiment No.	**Exp. 1**	**Exp. 2**	**Exp. 3**	**Exp. 4**	**Exp. 5**	**Exp. 6**	**Exp. 7**	**Exp. 8**	**Exp.9**	**Overall**
Test Start Time	14:04:29	2:04:29	14:04:29	18:26:53	1:26:53	8:26:53	15:26:53	22:26:53	5:26:53	
Test Start Date	12/9/15	12/10/15	14:04:29	10/12/15	11/12/15	11/12/15	11/12/15	11/12/15	12/12/15	
Experiment Duration (hrs.)	8	8	3	6	6	6	6	6	6	**55**
Mass Average [mg/m^3]	0.479	0.675	0.72	1.03	1.05	1.18	1.09	1.09	1.11	**0.99**
Mass Minimum [mg/m^3]	0.133	0.505	0.64	0.943	1.01	1.05	1.07	1.06	1.07	**0.13**
Mass Maximum [mg/m^3]	0.601	0.774	0.75	1.05	1.09	2.78	1.11	1.1	1.49	**2.78**
Mass TWA [mg/m^3]	0.479	0.675	0.326	0.772	0.789	0.881	0.818	0.816	0.829	**0.71**

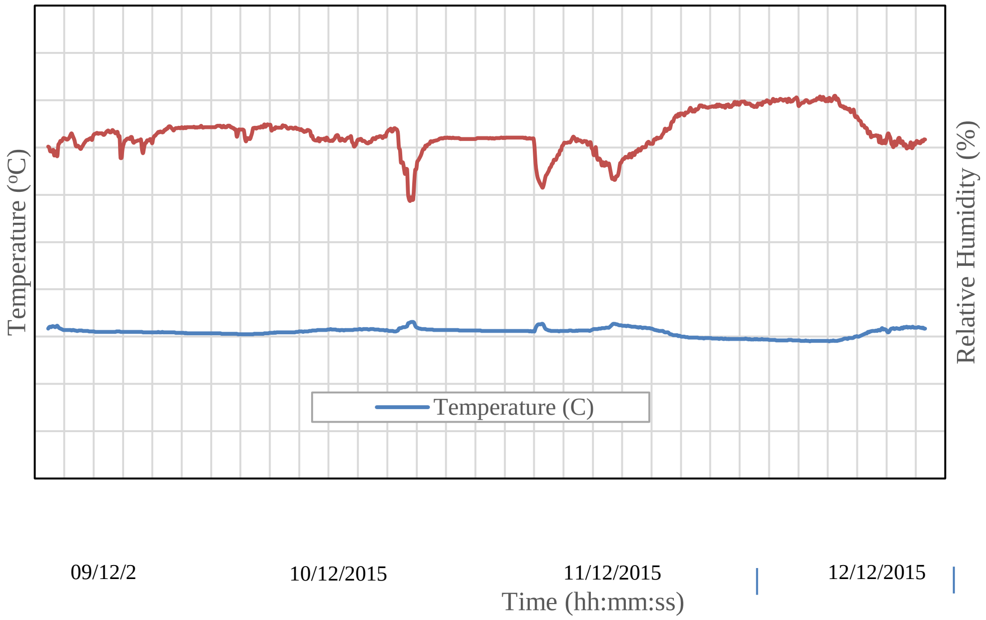


Fig- 6: Humidity and Temperature of the ambient air in Block E apartment

3.3.3 Ventilation performance

Figure 7 through Figure 9 shows the airflow pattern in the building under study at different wind speed. It can be seen from the figures that indoor airflow in the building is mainly characterized with recirculation zones in many localized regions. These vortices are also visible at high wind speed as revealed in Figure 8. Existence of these vortices highlights that air exchange in the building is insufficient. Cross ventilation in buildings is highly recommended to enhance effective air exchange. In general, the modeling results suggests, that the building exhibits poor airflow, which can pose uncomfortable conditions to human beings.

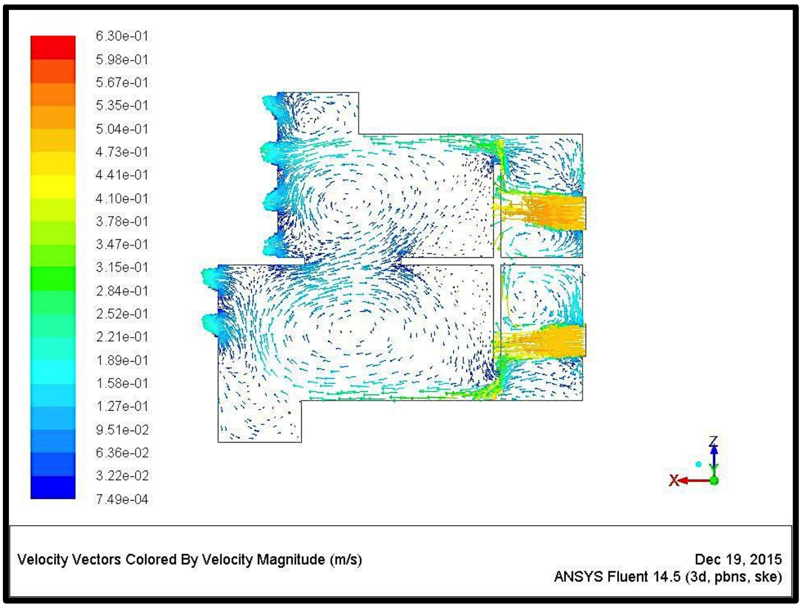


Fig-7: Airflow pattern in residential apartments at wind speed of 0.5 m/s

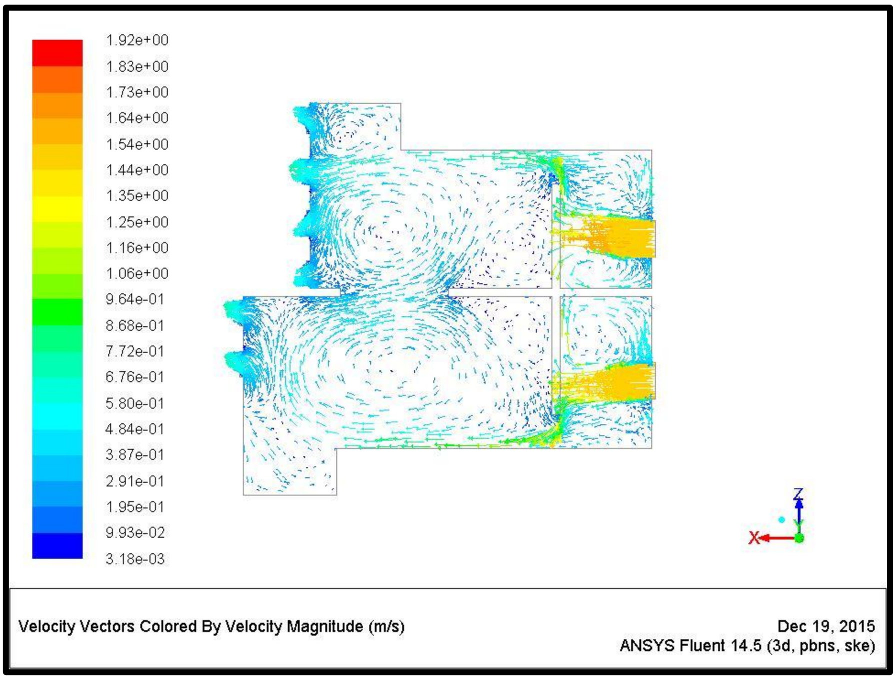


Fig- 8: Airflow pattern in residential apartments at wind speed of 1.5 m/s.

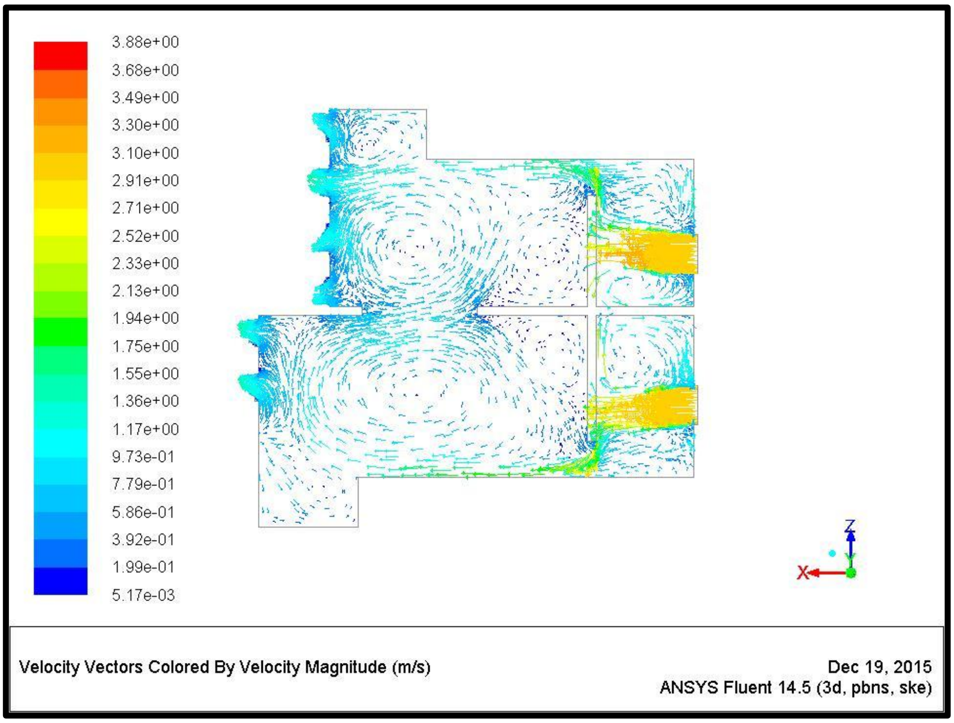


Fig-9: Airflow pattern in residential apartments at wind speed of 3 m/s

3.3.4 Emissions

The concentration of carbon monoxide (CO), Sulphur dioxide (SO_2), Nitrogen oxides (NOx) and Hydrocarbon carbons (HC) has been measured in the study area. The maximum concentration recorded in ambient air was 1 ppm for carbon monoxide and oxides of nitrogen while total hydrocarbon reached 2 ppm. Sulphur dioxide was not detected for all measurements taken. These findings suggest that emission level for the measured species are within Tanzanian Standards for Air Quality (EDMC2) and ASHRAE limit (ref Appendix A-1).

4. CONCLUSIONS AND RECOMMENDATIONS.

Visual inspection of the IST apartments and Preliminary indoor air quality assessment was conducted. In addition, modeling of airflow pattern was carried out to characterize air exchange in the building. The results show less provision of openings to capture natural air, bad choice of window type and size as well as position to allow for sufficient natural ventilation. Furthermore, levels of relative humidity are higher than recommended for human comfort and can lead to formation of bio-colonization. Particulate concentrations were found to be within ASHRAE limits whereby emissions concentration of CO, SO_2, NOx and HC gases were within their respective recommended thresholds. Airflow pattern was mainly dominated with vortices, which inhibits fresh air exchange in the building. In general, findings from this study reveal that, the air quality in the residential apartments is well below a satisfactory level of an apartment that is ventilated naturally. It is recommended that architects should design based on climatic condition of the site locality by open up the living spaces (to eliminate vortices) and enhance efficient natural ventilation in the building for energy efficient that requires no air conditioned to attain human comfort conditions. Government should put in place building codes for the design of living spaces in hot climate and establish mandatory guidelines for sustainable energy efficiency design.

5. REFERENCES

[1] Assali, I. M. (2015). “Sustainable Design as a Tool for Healthy Indoor Environment”. *International Journal of Engineering Research and Development , 11* (12), PP.36-44.

[2] Šenitková, Ingrid Juhásová, (2017). “Indoor Air Quality and Buildings Design”. *MATEC Web of Conferences.* EDP Sciences

[3] Yousef Al horr, Mohammed Arif, Martha Katafygiotou, Ahmed Mazroei, Amit Kaushik , Esam Elsarrag. (2016). “Impact of Indoor Environmental Quality on Occupant Well-being and Comfort: A review of the Literature”. *International Journal of Sustainable Built Environment, 5*, 1–11.

[4] Wargocki, P., Sundell, J., Bischof, W., Brundrett, G., Fanger, P.O., (2007). “Volatile Organic Compounds in Indoor Environment and Photocatalytic Oxidation: State of the Art”. *Environtal International 33 (5)* , 694–705.

[5] De Giuli, V., Da Pos, O., De Carli, M. (2012). “Indoor Environmental Quality and Pupil Perception in Italian Primary Schools”. *Build. Environ.* , 335–345.

[6] Jaakkola, M.S., Quansah, R., Hugg, T.T., Heikkinen, S.A., Jaakkola, J.J.,. (2013). “Association of Indoor Dampness and Molds with Rhinitis Risk: A Systematic rRview and Meta-Analysis”. *Journal of Allergy Clinical Immunology*. 132 (5), , 1099–1110.

[7] Wang, S., Ang, H., Tade, M.O., . (2007). “Volatile Organic Compounds in Indoor Environment and Photocatalytic oxidation: State of the Art”. *Environ. Int. 33 (5)* , 694–705.

[8] Wolkoff, P., Kjærgaard, S.K. (2007). “The Dichotomy of Relative Humidity on Indoor Air Quality”. *Enviromental International 33 (6)* , 850–857.

[9] Bako-Biro, Z.s., Clements-Croome, D.J., Kochhara, N., Awbia, H.B.,Williams, M.J., (2012). “Ventilation Rates in Schools and Pupils Perfomance. *Build. Environ*. 48, 215-233.

[10] Daisey, J.M., Angell, W.J., Apte, M.G.,. (2003). “Indoor Air Quality, Ventilation and Health Symptoms in Schools: An Analysis of Existing Information”. *Indoor Air, 13 (1)* , 53–64.

[11] Burge, S., Hedge, A., Wilson, S., Bass, J.H., Robertson, A. (1987). “Sick Building Syndrome: A Study of 4373 Office Workers”. *Occupational Hygine* 31 (4A) , 493–504

[12] Mendell, M.J., Smith, A.H. (1990). “Consistent Pattern of Elevated Symptoms in Air-conditioned Office Buildings: A Reanalysis of Epidemiologic Studies”. *Journal of Public Health* 80 (10) , 1193–1199.

[13] Hudnell, H.K., Otto, D.A., House, D.E., Mølhave, L. (1992). “Humans to a Volatile Organic Mixture. II. Sensory”. *Architecture Environtal Health* 47 (1) , 31–38.

[14] Šenitková,, Ingrid Juhásová, and EK Burdova. (2008). “Indoor Environmental Quality Assessment”. *Journal of Civil Engineering ,* 45-56.

[15] Šenitková, I. (2014). “Impact of Indoor Surface Materials on Perceived Air Quality”. *Material Science and Engineering 36* , 1-6.

[16] Malisa, A. E. (2007). "Situation, Challenge and Plans for Environmental Statistics in Tanzania". Environmental statistics. Addis Ababa.

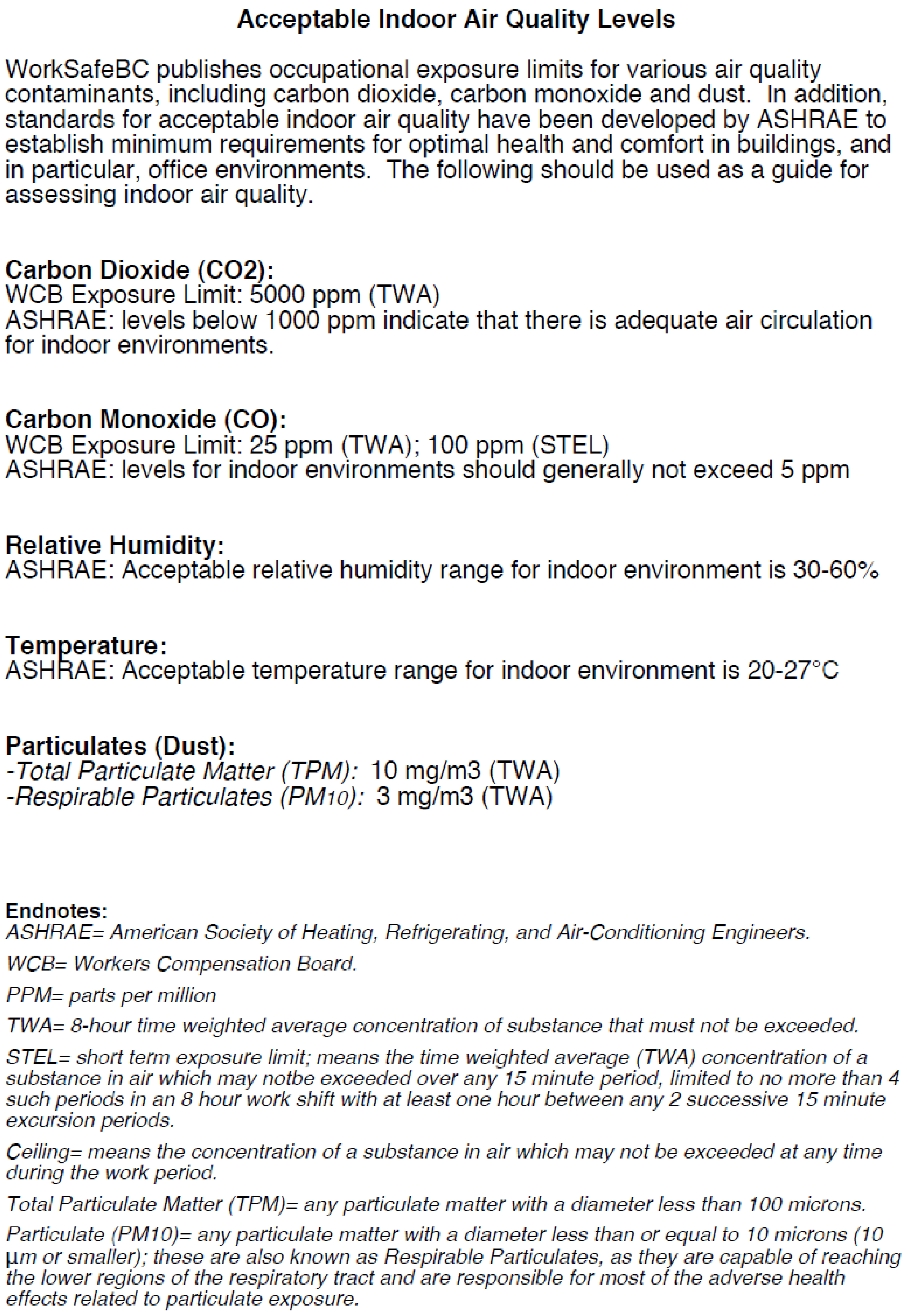
[17] Adedayo Ola and Stephen Oyetola. (2015). "Assessment of Window Types in Natural Ventilation of Hotels in Taraba State". *Journal of Environmental Health Science* 5(2) , 117-123

[18] R.P.Guimaraes., M.C.R. Carvalho, and F.A. Santos (2013), "The Influence of ceiling height in thermal comfort of buildings: A case study in Belo Horizonte, Brazil"., *International Journal for Housing Science*, Vol. 37, No.2 pp. 75-86.

BIOGRAPHY

Dr. Isabela W. Mtani is a registered Architect and a Research Fellow at Ardhi University in the Institute of Human Settlement Studies (IHSS). She holds a PhD degree in Engineering specializing on building materials science Master of Engineering Management and Bachelor of Architecture. She specializes in Building materials, Project management, Buildings Conservation and Housing.

Appendix A-1: Standard for-air quality



Acceptable Indoor Air Quality Levels

WorkSafeBC publishes occupational exposure limits for various air quality contaminants, including carbon dioxide, carbon monoxide and dust. In addition, standards for acceptable indoor air quality have been developed by ASHRAE to establish minimum requirements for optimal health and comfort in buildings, and in particular, office environments. The following should be used as a guide for assessing indoor air quality.

Carbon Dioxide (CO2):
WCB Exposure Limit: 5000 ppm (TWA)
ASHRAE: levels below 1000 ppm indicate that there is adequate air circulation for indoor environments.

Carbon Monoxide (CO):
WCB Exposure Limit: 25 ppm (TWA); 100 ppm (STEL)
ASHRAE: levels for indoor environments should generally not exceed 5 ppm

Relative Humidity:
ASHRAE: Acceptable relative humidity range for indoor environment is 30-60%

Temperature:
ASHRAE: Acceptable temperature range for indoor environment is 20-27°C

Particulates (Dust):
-*Total Particulate Matter (TPM):* 10 mg/m3 (TWA)
-*Respirable Particulates (PM$_{10}$):* 3 mg/m3 (TWA)

Endnotes:
ASHRAE= American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

WCB= Workers Compensation Board.

PPM= parts per million

TWA= 8-hour time weighted average concentration of substance that must not be exceeded.

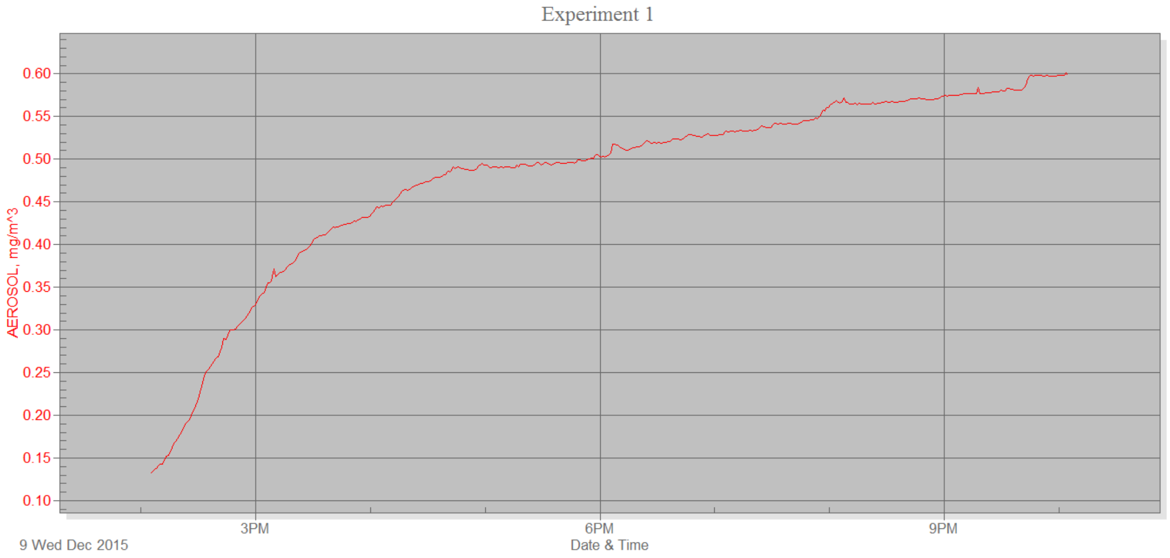
STEL= short term exposure limit; means the time weighted average (TWA) concentration of a substance in air which may notbe exceeded over any 15 minute period, limited to no more than 4 such periods in an 8 hour work shift with at least one hour between any 2 successive 15 minute excursion periods.

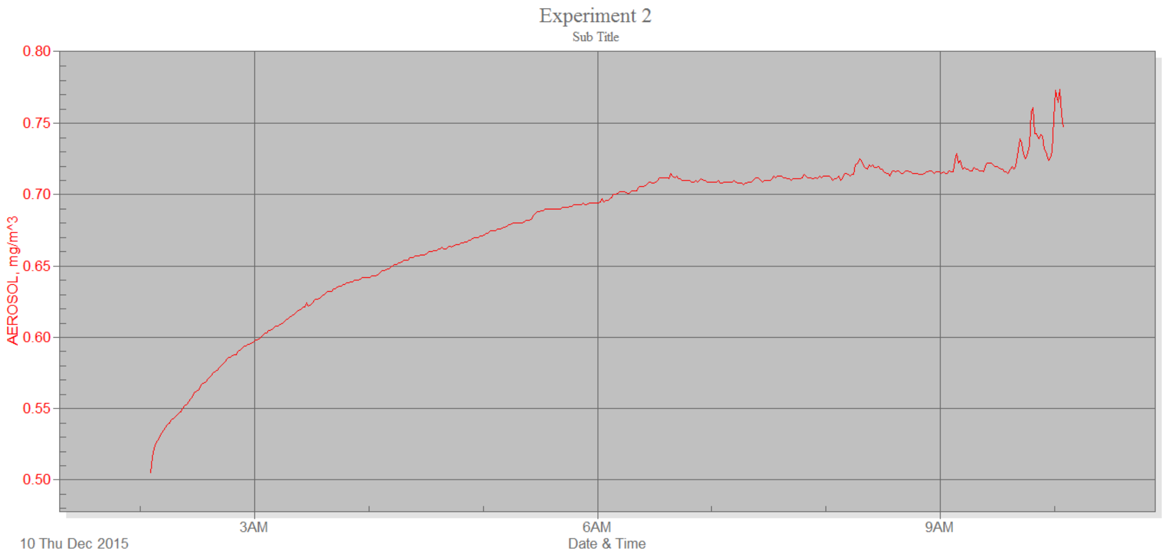
Ceiling= means the concentration of a substance in air which may not be exceeded at any time during the work period.

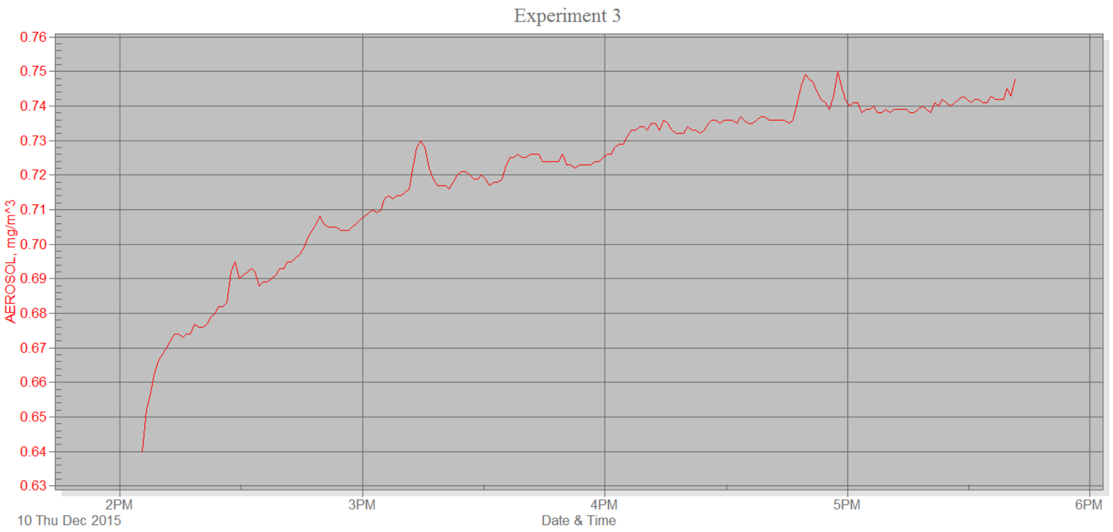
Total Particulate Matter (TPM)= any particulate matter with a diameter less than 100 microns.

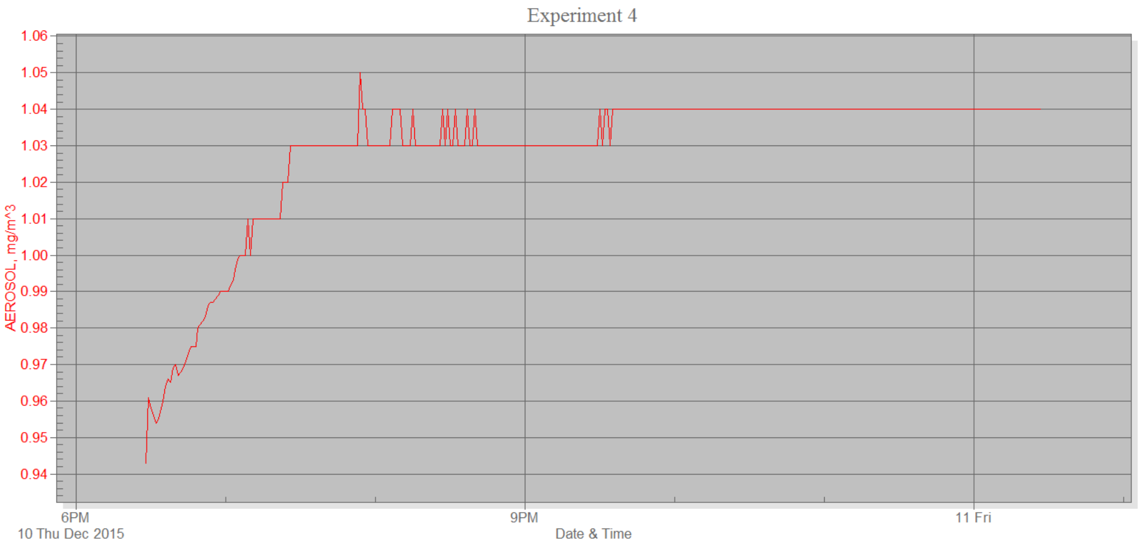
Particulate (PM10)= any particulate matter with a diameter less than or equal to 10 microns (10 µm or smaller); these are also known as Respirable Particulates, as they are capable of reaching the lower regions of the respiratory tract and are responsible for most of the adverse health effects related to particulate exposure.

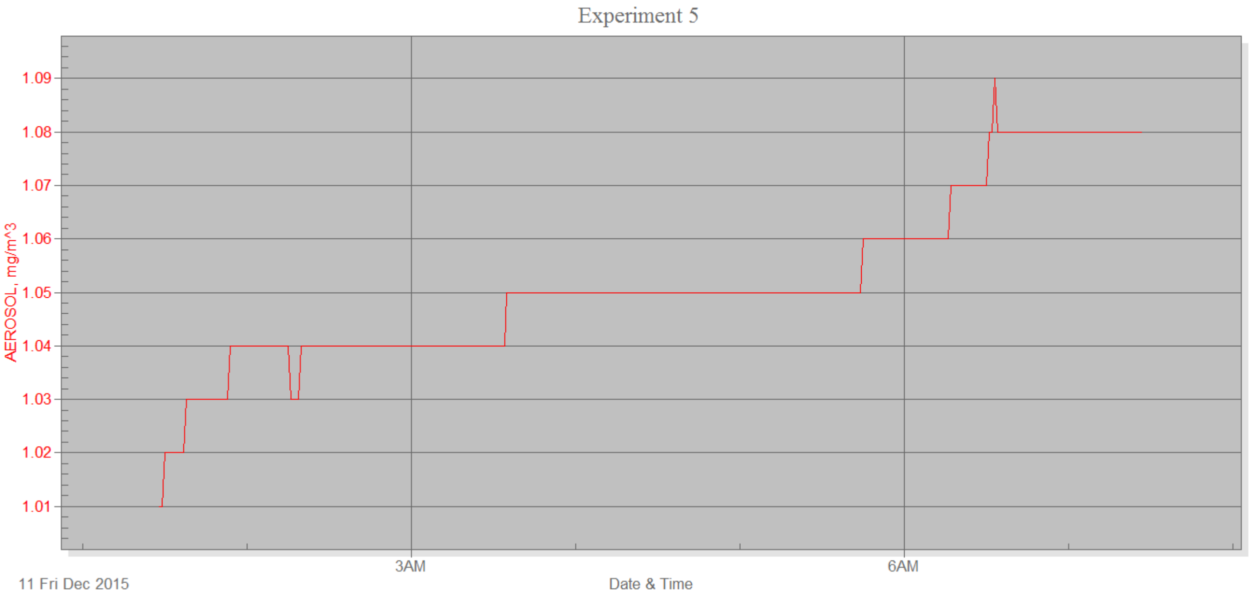
Appendix A-2: Particulate Data

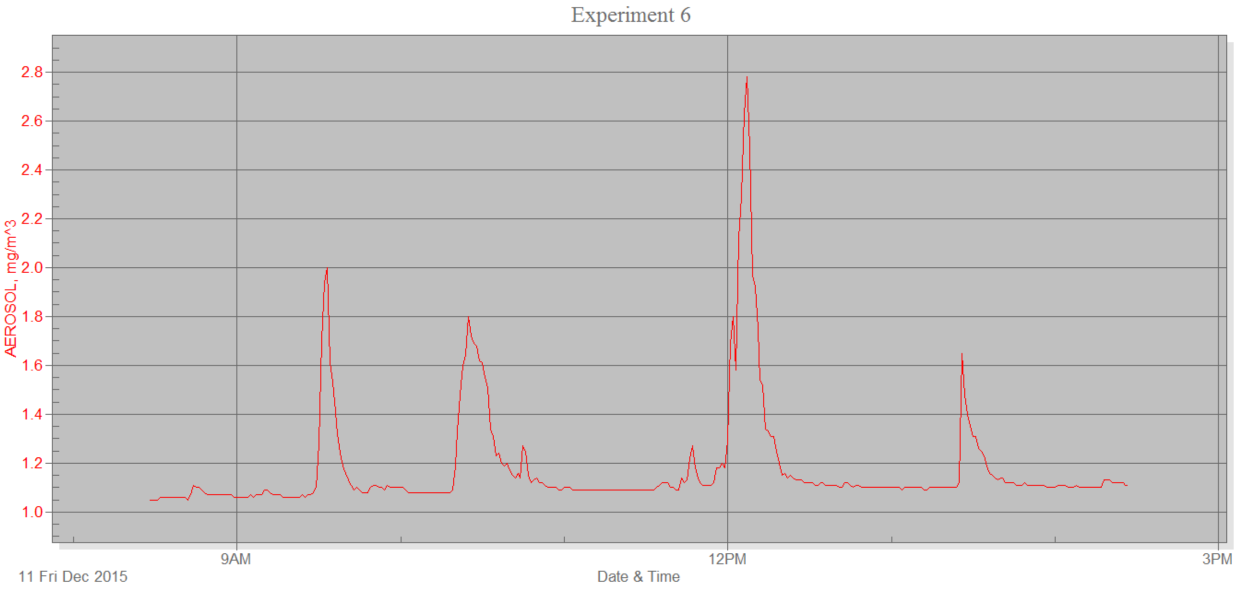

Experiment 1

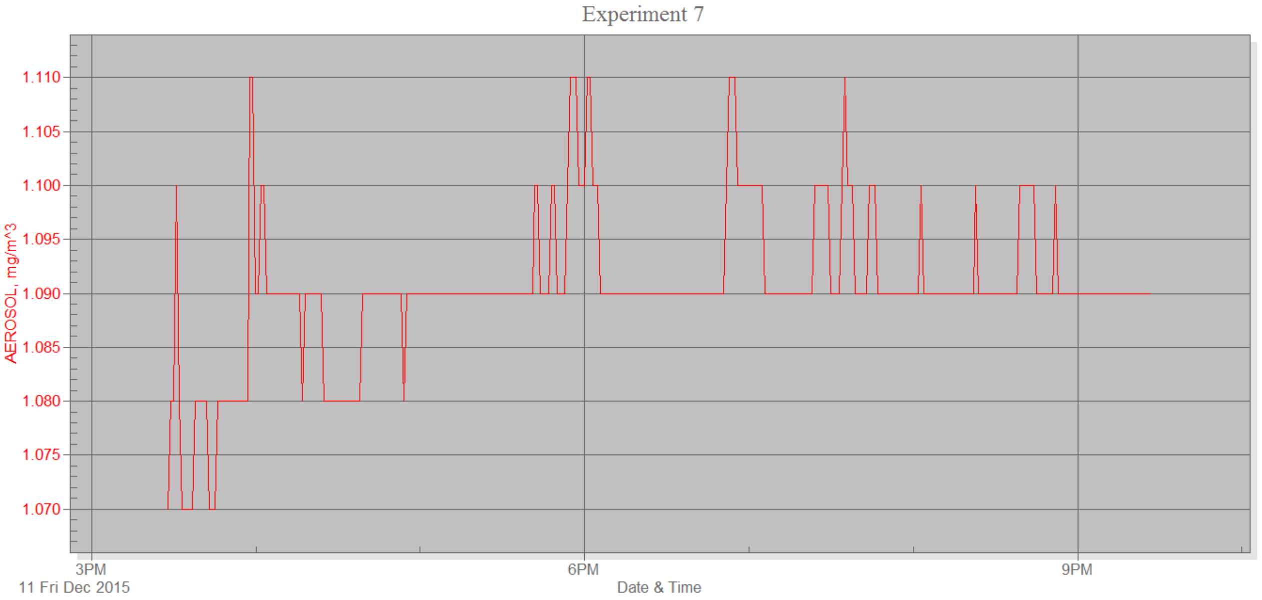

Experiment 2
Sub Title

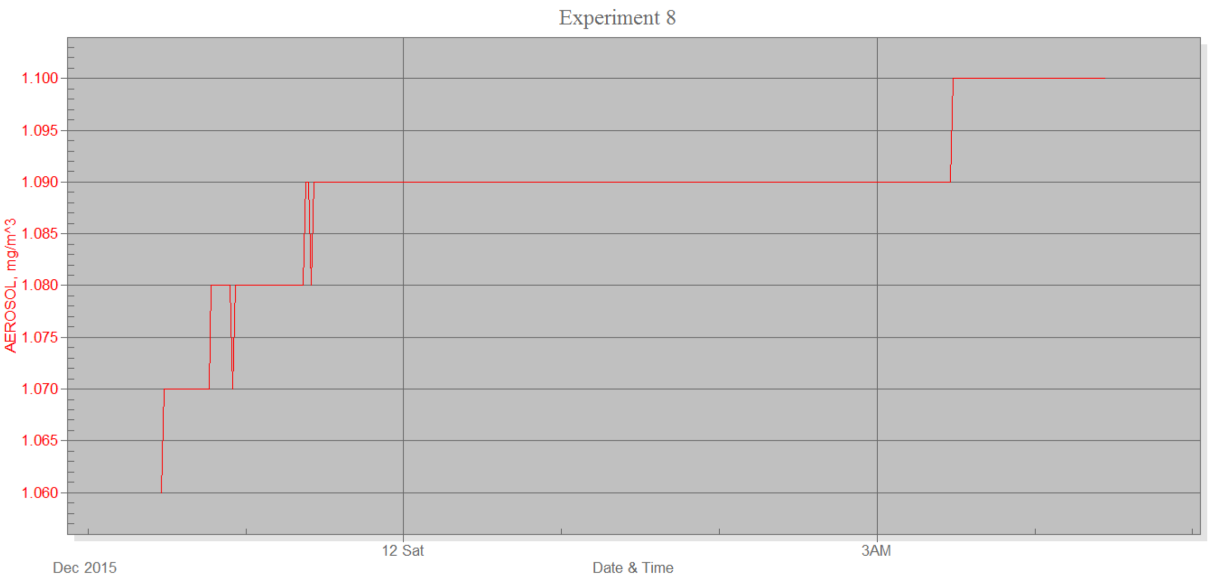

Experiment 3
AEROSOL, mg/m^3
0.76
0.75
0.74
0.73
0.72
0.71
0.70
0.69
0.68
0.67
0.66
0.65
0.64
0.63
2PM
3PM
4PM
5PM
6PM
10 Thu Dec 2015
Date & Time

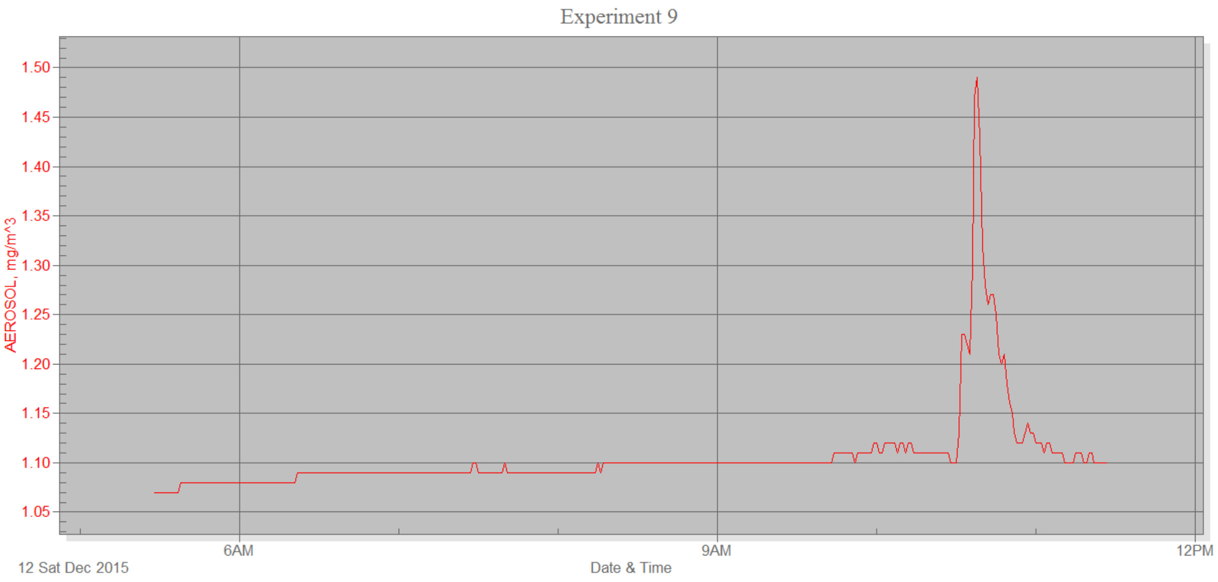

Experiment 4
AEROSOL, mg/m^3
1.06
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.95
0.94
6PM
9PM
11 Fri
10 Thu Dec 2015
Date & Time


Experiment 5
AEROSOL, mg/m^3
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
3AM
6AM
11 Fri Dec 2015
Date & Time


Experiment 6
AEROSOL, mg/m^3
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
9AM
12PM
3PM
11 Fri Dec 2015
Date & Time


Experiment 7
AEROSOL, mg/m^3
1.110
1.105
1.100
1.095
1.090
1.085
1.080
1.075
1.070
3PM
6PM
9PM
11 Fri Dec 2015
Date & Time


Experiment 8


Experiment 9