The impacts of outdoor concentration of nitrogen dioxide on its indoor level

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Abstract. This study examined the infiltration of oxides of nitrogen (NOx) from outdoor into the indoor environments in the commercial areas of Osogbo, Nigeria. Outdoor NOx concentrations were monitored at four different locations with a high volume of commercial and vehicular activities using Toxirae II NOx monitor. A control sampling point was also set at another location with no commercial and vehicular activities. The indoor concentrations at each location were simulated using IAQX 1.0f simulation tool of the US EPA. The mean measured outdoor NOx concentration over the entire commercial area ranged between 0.14 and 0.58 ppm with an average of 0.351 ppm but at the control point it ranged between 0.0 and 0.2 ppm with an average of 0.027 ppm. A simulation of the indoor concentration revealed an unhealthy indoor air quality. The stabilized indoor concentrations at commercial areas ranged between 0.054 and 0.169 ppm but it was 0.00917 ppm at the control point. The study establishes that emissions associated commercial activities may contribute significantly to indoor air quality degradation in an unplanned area thus calls for appropriate regulatory measures to protect public health.

Keywords: Vehicular activities, IAQX simulation tool, Electricity generators, Air quality.

1. Introduction
Indoor Air Quality (AIQ) has received tremendous attention in recent time due to a large amount of time mankind spend indoors [1] People typically spend a larger fraction of their time indoors: homes, workplaces, shopping malls and restaurants [2]. There is a rising anxiety over the infiltration into the indoor micro-environments of conventional air emissions generated outdoors. This concern is even more pertinent in developing countries where the unplanned nature of most cities could make the indoor environments direct recipient of outdoor emissions. Oxides of nitrogen constitute one of the criteria pollutants regulated by the US EPA. Various studies have reported harmful health impact of NOx [3], [4].

Vehicular activities have been identified as contributing significantly to ambient NOx in urban areas [5], [6], [7], [8], [9], [10], [11]. This is particularly significant since vehicle emissions may accumulate within the urban canopy prompting bothersome degrees of pollutants in structures (buildings)
close to hectic roads, especially during peak traffic periods. Short bursts of air pollution, coming about either from heavy traffic pollutants or poisonous episodes, are of specific worry because of the high indoor levels that may emerge thereafter. Other huge sources of air pollution include emissions from modern plants, boiler flues, incinerators, power plant, construction works and use of fossil-fuelled electricity generators which contribute to aerosols in many regions in Nigeria [12].

IAQX simulation software for indoor air quality and inhalation exposure is commonly used to for simulation of indoor air quality. It was developed by the U.S. Environmental Protection Agency in October, 2000 and was reviewed in December, 2004 with the latest version being IAQX 1.0f. It is a complete indoor air quality modelling package. The IAQX comprises five programs: GPS.EXE which is the general purpose simulation program, VBX.EVE which is a simulation program for VOC emission from solvent-based indoor coating materials, SPIE.EXE model for solvent spill in the indoor environment, SLAB.EXE which is a model for VOC emission from diffusion-controlled homogeneous slabs, and PM.EXE that is a model for indoor particulate matter. It is a software package that complements and supplements existing IAQ simulation program such as RISK (Sparks, 1996). IAQX is a user-friendly interface developed specially for Microsoft Windows and runs under Windows 95, 98, Me, NT, 2000, XP and higher ones. This kit was used by Adefeso et al., (2012) to model the influx Carbon monoxide (CO) from portable power generator on Indoor Air Quality.

In Nigeria, air quality studies have focused extensively on outdoor environments and data gap clearly exists for the indoor environment. In this study, IAQX simulation tool kit of version 1.0f has been used to simulate indoor air levels of NOx in commercial area of Osogbo an emerging city in Nigeria. This was with a view to providing the missing data gap for indoor environments and to call for regulatory measures to protect public health.

2. Materials and Methods

2.1 Description of study area
Osogbo, the capital city of Osun State, Nigeria is an emerging city in Nigeria with increasing volume of commercial and vehicular activities day after day. It is located on geographical coordinates 7° 46’ North, 4° 34’ East. It has a population of about 3.4 million people (FRNOG, 2009). There are quite a number of small to medium scale enterprises which make use of fossil fuel generators to meet the short falls in their energy requirement. The city is largely unplanned with commercial and vehicular activities co-existing together with various indoor environments. For sampling exercises, four commercial areas labelled A, B, C and D were investigated. A control sampling point E where there were no commercial activities was also set up.

2.2 Measurement of outdoor parameters
ToxiRAE II personal gas NOx monitor was used to measure the ambient NOx concentrations. Also, the Kestrel 4500 pocket weather tracker was set up to measure the ambient wind speeds at each sampling location. Measurements with these devices were conducted in each sampling location that ranged between 1.5 m and 2.0 m away from the road and above the ground. Readings were taken at 2 minutes interval on averaging time of 1 hour throughout the sampling period.

2.3 Determination of air exchange per hour (ACH) of the microenvironments
ACH is the ratio of volumetric flow rate of air per unit of a space (Sparks, 1996). The air exchange rates were calculated using Bouhamba et al., (2000) formula with the guiding equation given below.

\[ ACH = \frac{(Q_1 \times Q_2 \times Q_3)}{V} \] (1)

Where:

\[ ACH = \text{Air exchange rate per hour} \]
\[ Q_i = \text{Air volumetric flow rate through infiltration} \]
\[ Q_n = \text{air volumetric flow rate through openings} \]
\[ Q_c = \text{air volumetric flow rate through air conditioning} \]
Qi and Qc are not considered in this study for Qi is significantly small and Qc is absent, therefore the equation reduces to

\[ ACH = Q_n V \] \hspace{1cm} (2)

Where:

\[ Q_n = UC_v A_r \] \hspace{1cm} (3)

\[ V = \text{volume of micro environment} \]
\[ C_v = \text{effective opening factor (0.5 for perpendicular wind, 0.25 for diagonal wind)} \]
\[ A_r = \text{actual opening area for doors and windows} \]
\[ U = \text{average wind speed} \]

\[ ACH = C_v A_r U \] \hspace{1cm} (4)

The parameters of the micro environment investigated are summarized in Table 1.

### 2.4 IAQX simulation tool and procedure

The GPS.EXE which is the general-purpose simulation program of the IAQX Tool was used in this work for indoor air quality modelling. The input to the IAQX simulator included measured outdoor (NOx concentration and wind speed), computed micro environment (Volumes of indoor environment, volumetric flow rate air through openings and actual opening area for doors and windows) and literature (effective opening factor) parameters. The computer interfaces of the GPS.EXE program of the modelling tool were followed for the inputs to be entered. It contains five interfaces in all which are building configuration interface, ventilation interface, sources interface, conditions interface and output interface. The building configurations (volumes of microenvironments) were entered through the building interface, the air exchange rates through the ventilation interface, the mean outdoor NOx concentrations through the sources interface, the simulation periods through the condition interface while the output interface gave the results of the IAQX runs. Five scenarios were created and in each scenario, the building modelled was assumed to be in each of the sampling locations with simulation period of 2.5 hours. Sinks and initial concentrations of NOx in each microenvironment were assumed zero.

### Table 1: Summary of the Evaluated ACHs for the Microenvironments

| Environment | \( C_v \) | \( A_r \) | \( U(m/s) \) | \( Q_n(m^3/hr) \) | \( V(m^3) \) | \( ACH(h^{-1}) \) |
|-------------|----------|----------|-------------|----------------|------------|----------------|
| Guest Room  | 0.5      | 5.35     | 0.506       | 4874.40        | 31.752     | 153.51         |
| Bedroom     | 0.5      | 5.35     | 0.506       | 4874.40        | 26.460     | 184.22         |
| Masters B   | 0.5      | 5.35     | 0.506       | 4874.40        | 31.712     | 153.51         |
| Madams B    | 0.5      | 5.35     | 0.506       | 4874.40        | 31.712     | 153.51         |
| Main Lounge | 0.5      | 5.35     | 0.506       | 5355.50        | 50.954     | 105.10         |
| Kitchen     | 0.5      | 5.35     | 0.506       | 7158.89        | 38.367     | 186.59         |
| Veranda     | 0.5      | 5.35     | 0.506       | 9873.07        | 8.944      | 1103.89        |
| Passage     | 0.5      | 5.35     | 0.506       | 7213.54        | 35.060     | 205.75         |

### 3. Results and Discussion

#### 3.1 Outdoor NOx levels
Tables 2 and 3 summarize the measured outdoor concentrations of NO\textsubscript{x} and wind speeds at the five sampling locations. The mean outdoor concentration of NO\textsubscript{x} in the commercial area ranged between 0.14-0.58 ppm (Table 2). These were higher than the 1-hr averaging period NO\textsubscript{x} standard of 0.1 ppm and 0.075-0.113 ppm as reported by FEPA (1991), respectively. However, the mean NO\textsubscript{x} at sampling location E (Table 2), a non-commercial area (Control experiment), was 0.0267 which is lower than the US and Nigerian FMENV standards. These trends were so because various NO\textsubscript{x} emission sources (vehicular activity, fossil fuel generators) which were present in the commercial areas were highly reduced at location E which is strictly residential.

3.2 Indoor NO\textsubscript{x} Concentration

Figures 1-5 represent the indoor levels of NO\textsubscript{x} at the five sampling locations investigated in this study. At constant air exchange rate (ACH), volume of the microenvironments and infiltration factor, gaseous pollutant concentration influx on indoor air quality is a function of outdoor air quality. This agrees with the proof that no matter the degree of isolation of an indoor environment, it is an extension of the outdoor atmosphere and a pollutant such as NO\textsubscript{x} readily penetrates the indoor environments (Yocom, 1982). For a simulation period of 2.5 hours, the Indoor NO\textsubscript{x} concentration as shown in Figures 1-5 rose exponentially with time and later stabilized in all the microenvironments. The stabilized indoor NO\textsubscript{x} levels in locations A, B and D were 0.169 ppm, 0.137 ppm and 0.081 ppm respectively and were above US and Nigeria NO\textsubscript{x} standards while that of location E was 0.00917 ppm, this is below US and Nigerian NO\textsubscript{x} standards.

The more the commercial activities involving the use of fossil fuel generators and traffic, the higher the NO\textsubscript{x} concentration in the outdoor air. It was also observed that NO\textsubscript{x} concentrations in microenvironments of a building in a polluted area increased gradually according to air exchange rates of the microenvironments. Therefore, outdoor air pollutant has impact on the indoor air pollutant concentration profile as pointed out by Carlaws (2007). When indoor sources of NO\textsubscript{x} concentrations are absent, the outdoor concentration pattern over a long averaging time will be a good predictor of indoor NO\textsubscript{x} concentrations (Yocom, 1982). Again Figures 1-5 reveal that the indoor NO\textsubscript{x} levels would reach their highest concentrations and stabilize as long as the outdoor sources are not removed and the ventilation rate had no impact on the reduction or removal of indoor NO\textsubscript{x}.

| Table 2: Measured Outdoor NO\textsubscript{x} Concentration |
|-----------------------------------------------------------|
| Parameter       | A   | B   | C   | D   | E   |
| Minimum         | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| Maximum         | 0.5 | 0.6 | 0.4 | 0.4 | 0.2 |
| Mean            | 0.5800 | 0.4633 | 0.1433 | 0.2166 | 0.02667 |
| Median          | 0.6 | 0.5 | 0.2 | 0.2 | 0.0 |
| Mode            | 0.1 | 0.1 | 0.2 | 0.3 | 0.0 |
| Range           | 0.8 | 0.3 | 0.4 | 0.4 | 0.2 |
| Standard error  | 0.0147 | 0.01221 | 0.02783 | 0.02716 | 0.01168 |
| Standard deviation | 0.08052 | 0.06687 | 0.15241 | 0.14875 | 0.06937 |
| Confidence interval (95%) | 0.8 | 0.6 | 0.4 | 0.4 | 0.2 |
Table 3: Measured with speed

| Parameters   | A      | B      | C      | D      | E      |
|--------------|--------|--------|--------|--------|--------|
| Minimum      | 0.0    | 0.0    | 0.0    | 0.0    | 0.0    |
| Maximum      | 2.9    | 2.8    | 2.3    | 2.1    | 2.4    |
| Mean         | 0.40333| 0.5900 | 0.4300 | 0.4533 | 0.4900 |
| Median       | 0.15   | 0.4    | 0.25   | 0.4    | 0.3    |
| Mode         | 0.6    | 0.7    | 0.7    | 0.4    | 0.6    |
| Range        | 2.9    | 2.8    | 2.3    | 2.1    | 2.4    |
| Standard error | 0.10949 | 0.12009 | 0.09385 | 0.082589 | 0.1081 |
| Standard deviation | 0.10949 | 0.65777 | 0.51404 | 0.45238 | 0.5921 |
| Confidence interval (95%) | 1.4    | 2.2    | 1.5    | 1.4    | 2.1    |

Figure 1: Concentration-Time Plot of NOx in Microenvironments, Location A
Figure 2: Concentration-Time Plot of NO\textsubscript{x} in Microenvironments, Location B

Figure 3: Concentration-Time Plot of NO\textsubscript{x} in Microenvironments, Location C
4. Conclusion
The effects of outdoor air polluted by NO\textsubscript{x} on indoor NO\textsubscript{x} levels were studied using IAQX simulation protocol in Osogbo an emerging city in south west Nigeria. From the study it was concluded that the concentration of NO\textsubscript{x} emitted as a result of commercial activities in the outdoor environments exerted significant effect on the indoor air quality. The stabilized concentrations of NO\textsubscript{x} in the commercial areas exceeded both the US EPA and FMENV limits. A sufficiently high outdoor NO\textsubscript{x} concentration which could lead to detrimental indoor levels could occur during rush hours which may aggravate the health conditions of vulnerable groups (Aged, children and people with respiratory diseases) significantly. It is
suggested that careful planning be evolved to delineate commercial and various indoor environment such as schools, residential buildings and hospitals.

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