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Environmental Impact of Portable Power Generator on Indoor Air Quality

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Abstract. Increased demand for power and the low generation capacity of the country has led to increased use of alternate sources for electricity in homes and offices in Nigeria. Carbon monoxide (CO) emission from these sources has become a major indoor air pollution problem across the country and elsewhere with same power shortage scenario. This study determined the emission factors of CO from gasoline-powered portable power generators (PPG). It evaluated the effects of the CO influx on the indoor air quality and identified appropriate ways of maintaining the ambient concentrations below the safe level. Outdoor-indoor exchange of CO concentration was determined by modeling a number of scenarios of PPG operated outdoor using simulation tool kit for Indoor Air Quality and Inhalation Exposure (IAQX) model. The source CO concentration from PPG was found to be very high at 24.289 x 10^3 mg/m^3. The CO emission factors were obtained as 2.2366 x10^3 kg/m^3 of fuel consumed and 9.5411 x 10^6 kg/hr of activity. The results showed that high air exchange rate allowed CO concentrations to decay fast while low air exchange rates led to accumulation of CO indoor. It was found that a PPG should not be placed at least 10 meters from the building.

Keywords: CO emission, Indoor air quality, Emission factors, Air Quality Model, Portable power generator

1. Introduction

Indoor air quality (IAQ) has gained great attention in recent years, chiefly due to the large amount of time people spend indoors [1]. The World Health Organization constitution emphasized the right to a healthy indoor environment as a human right. The right to a healthy indoor environment includes the right to breathe clean air, to thermal comfort, visual health and comfort [2]. People typically spend a large fraction of their time indoors, homes, workplaces, shopping malls and restaurants [3]. In developing countries, women, who are normally responsible for food preparation and cooking, the infants and young children who spend time around their mother near the cooking area, are mostly exposed to health problems associated with indoor pollution [4]. Studies undertaken for air pollution abatement programs [2-4] confirmed a difference in indoor and outdoor air quality and pollutants.

Indoor air quality is determined by infiltration (uncontrolled ingress of outdoor air through the building fabric), ventilation (intentional transport of outdoor air via natural or mechanical ventilation) and low infiltration. Inadequate ventilation can increase indoor levels of air pollutants [5]. The combined effect of indoor sources of pollutants and infiltration of pollutants generated outdoors leads to the concentrations of some pollutants being higher indoors than out, with concentrations high enough to have an adverse impact on health.

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The latter observation had led to a UK government advisory group concluding that exposure to pollutants generated outdoors was likely to largely occur indoors [6]. Pollutants are generated through indoor activities such as cooking and smoking (particulates, oxide of carbon and nitrogen), cleaning (volatile organic compounds like monoterpenes) etc. [7]. Some indoor pollutants are formed outdoors (vehicles, generators and other area sources) but make their way inside through doors, windows or ventilation systems, or infiltrate the fabric of the building [6].

CO is a colourless, odourless, tasteless, non-irritating and toxic gas produced primarily during the incomplete combustion of carbonaceous fuels and substances [8]. CO poisoning is responsible for the death of more than 50% of the fatal poisonings reported in many countries [9]. The severity of CO poisoning is dependent on concentration, length of exposure, and the general underlying health status of the exposed individual. Because carboxy-heamoglobin concentrations in blood are cumulative over time, prolonged exposure to low concentrations can result in considerable health effects [8]. A portable electric power generator (PPG) is a gasoline or diesel-powered device which provides temporary electrical power up to certain wattage and designed for outdoor use. Users often place generators near or in their homes due to generator theft and noise to neighbors [5]. U.S Consumer Product Safety Commission reported that five out of 104 deaths caused by generator carbon monoxide (CO) poisoning were associated with a generator that was placed outside the home near open windows, doors, or vents [10]. In Nigeria, owing to epileptic supply of electricity, there is continuous increase in the use of portable electricity generators. It was reported that use of PPG in India urban areas increased the indoor concentration of CO [1]. The effects of exposure to high concentrations of CO had resulted in a number of deaths in Nigeria where more than 60 people suffocated to death in 2008 alone [11].

Several computer modeling techniques have been developed for indoor air quality studies. Chaloulakou and Mavroidis [12] used the mass-balance formulation developed by Hayes [13] to simulate indoor concentrations of CO in a public school building in Athens, Greece. An indoor air quality model of homes in UK used a probabilistic model (INDAIR) to predict air pollutants (NO_2, CO, PM_{10} and $PM_{2.5}$) concentrations in home microenvironments in the UK [14]. Montoya *et al.* [15] used various models for estimating indoor concentration as a function of outdoor concentration in the event of chemical attack involving toxic substances. Indoor concentration of pollutants is related to outdoor concentration. This study provides some insights for a safe operation of a portable generator and establishes influence on indoor air quality as related to CO concentration. Scenarios parameters considered for the research were natural ventilation conditions, constant emission factor for the PPG, generator positioned in verandah and hallway respectively and windows and doors were assumed open.

2. Materials and Methods

Hourly measurements of mean CO concentrations in ambient environment and wind speed were conducted for four weeks in four field locations. The CO concentration in ambient environment was measured using ToxiRAE II CO monitor. Wind speed was measured with Turbo Flow Meter 271 (Davis Instruments). The emission rate of CO from the PPG was measured using EGA4 combustion analyzer. EGA4 combustion analyzer was used for source emission measurement from the generator. The gas is sampled and aspirated through the probe with a primary pump powered at constant voltage. The ToxiRAE CO analyzer was used for the ambient measurements of CO concentrations. The experimental works carried out in this study included: i) determination of emission factor of CO for some significant indoor activities, ii) determination of emission factor of CO from a 450W air cooled TG950 portable generator (Tiger Power) and iii) evaluation of CO concentration influx from PPG with an IAQX model. The emitted CO concentrations (mg/m^3 and ppm), exhaust velocity (m/s) and emission factors (mg/GJ and mg/kW) were determined from the generator to obtain emission factors and exhaust flowrate. The CO exhaust emission concentrations and its velocity (to determine exhaust flow rate) from the generator were measured with the EGA4 combustion analyzer and the turbo flow meter. Four locations were selected for ambient measurement of CO concentrations. Samplings were carried out in these locations at height 1.50 m ground level. One of the locations serves as control which was mainly residential area with no commercial activity and very low motor vehicle density (Table 1).

3. Indoor Air Quality Modeling Protocol

The IAQX Model used in this study is a user-friendly interface for USEPA indoor air quality models. The building modeled for this study has fixed data, volumes of all indoor microenvironments, volumetric flow rates between indoor and outdoor environments, emission sources and its operating hours. A number of scenarios were created to represent real life PPG operations (Table 2) in various locations. The indoor micro environment in the building considered comprised of six microenvironments which are living room, two bedrooms, hallway, verandah, and kitchen (Figure 1). In this study, emissions from the identified sources (indoor/outdoor emission sources) were considered as part of input parameters into the modeling tool.

Table 1: Traffic Densities in Various Locations

s/n	Location	Motor Vehicle Count per Hour	Motorcycle Count per Hour
1	A	1740	2940
2	B	2580	4620
3	C	1800	3660
4	D	27	88

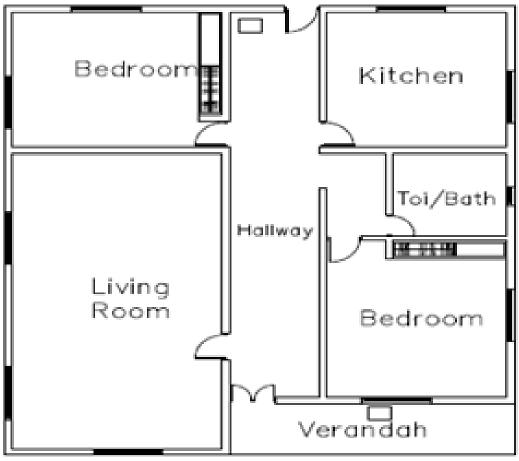

Fig. 1: Building plan for modeled building

Table 2: Possible Combinations of Indoor, Outdoor Source and ACH Scenarios

s	Outdoor Source	Indoor Source	PPG Location
1	Gen (4-8 hr)	CA_b + MsC	verandah
2	Gen (24 hr)	MsC	verandah
3	Gen (24 hr)	No source	verandah
4	Gen (24 hr)	No source	prescribed location

CA_a= Cooking activities with LPG, CA_b = Cooking activities with kerosene/charcoals/coal,
CA_{b+} = Cooking activities with kerosene + (charcoals/coal),
MSc = Mosquito coils, Inc = Incenses, Gen = Generator, ACH = Air change per hour.
(4-8 hr) = 4 hr in the morning and 8 hr in the night; (24 hr) = for a whole day

4. Results and Discussion

The contribution CO emission concentration from the PPG was very high and the implication of this on IAQ threatens indoor safety. Source CO concentration from PPG was 2.4289 x 10^4 mg/m^3, a very high CO concentration. The CO emission factors for the PPG were determined to be 2.237 x10^3 kg/m^3 of gasoline consumed and 9.541 x 10^6 kg/hr of activity. This is higher than the operational emission factor of 1.00 x 10^6

kg/hr reported [16]. The ambient CO concentrations at designated locations were obtained to be in following ranges - A (0.0 - 109.0 ppm), B (0.0 - 125.0 ppm), C (0.0 - 42.0 ppm) and (0.0 -12.0 ppm) while the mean CO concentrations was 11.901 $\pm$ 10.613 ppm. The wind speed measured at those designated locations are A (0.0 m/s and 1.8 m/s), B (of 0.0 m/s and of 1.20 m/s), C (of 0.0 m/s and of 3.20 m/s) and D (of 0.0 m/s and of 2.10 m/s). The overall mean wind speed was 0.1742 $\pm$ 0.2911 m/s. The values obtained for CO is higher than 1.10 ppm reported at 0.6 m/s wind speed [17]. The highest CO concentration was obtained in the hallway (Figure 2) - 9.58 x 10^4mg/m^3. Also the following high CO concentrations were obtained in rooms from the scenarios as: 1.28 x 10^4 mg/m^3 in Living room, 4.78 x 10^3 mg/m^3 in Bedroom2, 4.79 x 10^4mg/m^3 in Bedroom and 9.58 x 10^4mg/m^3 in Hallway. However, values obtained for last scenario (Figure 2 (d) are below 10 ppm [18]. Scenario 3 showed that low air exchange rate caused accumulation of CO indoor as the concentration could not decay to zero for some period of time. This agrees with [19] which reported that wind speeds had very little effect on outdoor CO concentration levels and higher wind speeds resulted in a lower indoor level in absence of indoor sources. It was found that an inverse relationship exists between wind speeds and indoor concentrations (regardless of the wind directions) since low wind speeds favor accumulations. The results from the model revealed that the hallway CO concentration was the highest compared to other rooms in the building (Figure 2) and far exceeded the indoor air quality standard of 10 ppm. The air exchange rate had an impact on the CO concentration profile as the strength of dilution or decay of indoor CO level is a function of air volumetric flow rate in and out of those microenvironments. It was noted that the scenarios which had highest CO concentrations indoor and hence pose a serious danger is when the PPG was kept in the hallway in the night. The CO level remained constant. This is responsible for death from CO poisoning when using the PPG indoor and overnight. Scenarios 4 with the PPG kept in a prescribed location from the building, operated for 24 hr with windows and doors opened in the morning but doors closed in the night while windows were partially opened gave very low CO concentrations in indoor environment. The values obtained were below the standard (10 ppm).This scenario or with PPG run intermittently is the safest way to use PPG in homes.

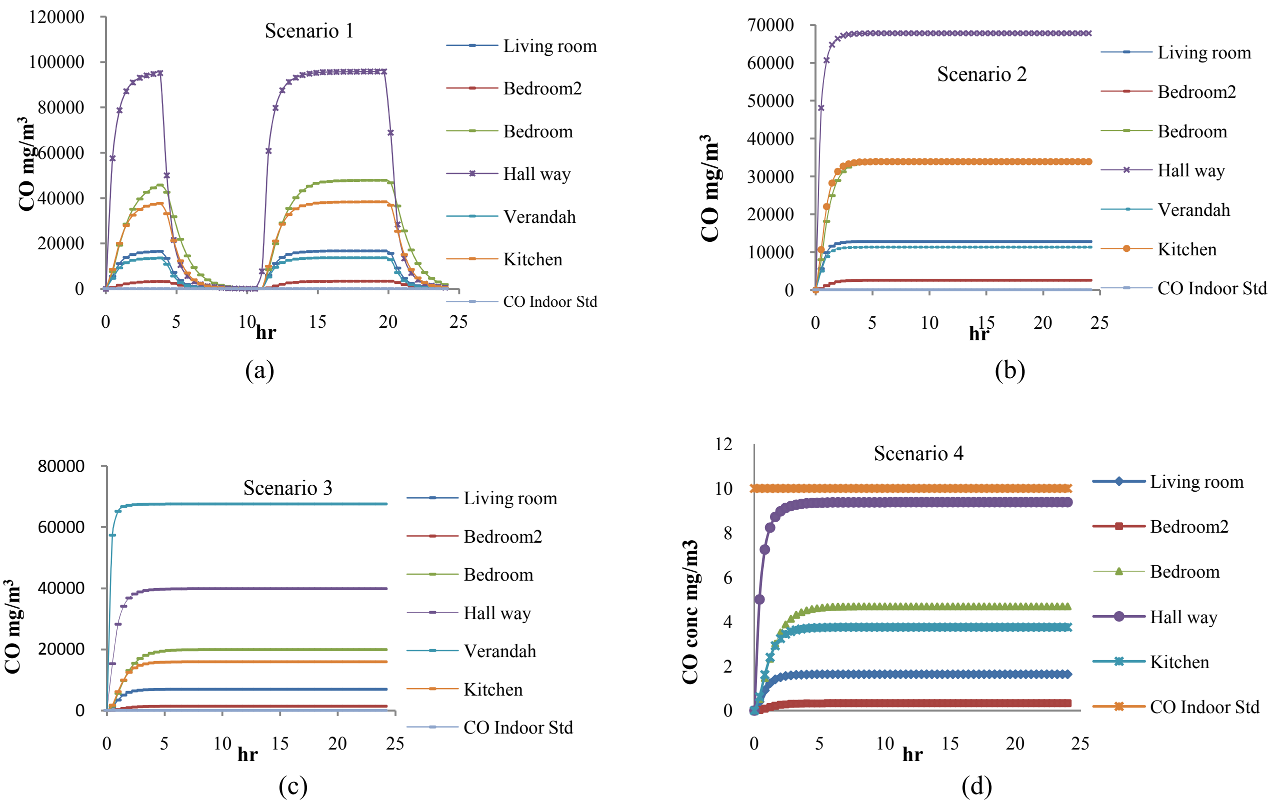

Fig. 2: CO concentration profile in microenvironments for different PPG application scenario (refer to Table 2)

5. Conclusions

The CO concentrations emitted by PPG were very high as indicated by the source measurement and a high emission rate of CO concentration that poses a threat to life if operated indoors or at close proximity (less than the safe distance of 10 m downwind) to buildings. Outdoor-indoor relationship of CO concentration was established. Natural ventilation rates affect level of concentrations of CO Indoor. Under low ventilation rates, the CO concentrations did not decay to zero value even many hours after the PPG had been shut down. Under high ventilation rates, the indoor CO concentration did decay to zero in few minutes. Operating the PPG indoor resulted in high accumulation of CO concentrations indoor which could cause death within short period of time.

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