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Evaluation of the Carbon Monoxide Emissions of Electric Power Generators Used in Buildings in Ibadan Metropolis, Nigeria

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Abstract: The poor supply of electricity to different settlements in Nigeria, continuing over the years now, has forced building occupants to shift to dependence on generators. This study determines the outdoor and indoor carbon monoxide levels relating to the use of generators in both residential and commercial buildings and assesses their impact on the users and environment. The study was carried out in Ibadan Metropolis, Nigeria, which was divided into core, transition and suburban zones. Consequently, five (5) residential and commercial buildings were purposively selected in each of the zones of the study area. The HT-1000 digital LCD carbon monoxide meter was used to take measurements of the emissions of carbon monoxide with conformity to NESREA and OSHA standards. The outdoor emission levels of carbon monoxide before or during the use of generators were taken at 0, 2 and 4m, respectively, from the external walls of the buildings sampled and the corresponding indoor measurements were taken internally at 1.2-1.5m above floor area. The data collected were analysed with the use of statistical methods, such as t-test, trend analysis and Kolmogorov Smirnov test. The results show that the values of outdoor and indoor measurements of carbon monoxide emissions levels were the highest in buildings in the core zone either before or during the use of generating sets. Reduced carbon monoxide levels during the use of generators were obtained at distance limits beyond 2m from the external walls of buildings across the zones of the study area. In view of the measurements taken and the obtained results ranging above the limits set by statutory bodies, as well as the attendant effects on the environment and building occupants, it is recommended that users of the generators should be forced to position them in enclosures located away from external walls of buildings and that the government should license only sales of generating sets with emission control mechanisms.

Keywords: environment, electricity, buildings, generators, carbon monoxide emissions.

JEL codes: Q41, Q53

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1. Introduction

The increase in population globally is taking a heavier and heavier toll on the environment through the construction of buildings necessary for the existence of human beings (Ojoye and Yahya, 2007). Globally, urban centres have continued to witness an especially rapid growth for more than half a century now (Kombe and Kreibich, 2000). This shows that man's activity directed at coping with population challenges, creating more space for residences and other pressing urban land uses is on the increase. The resultant effects of these are global destruction of flora resources, environmental pollution, climate change and depletion of the ozone layer (Vernon, 2002; UN-Habitat, 2003; Ojoye and Yahya, 2007; Eze and Muhammad, 2010). The functioning of buildings, their use by occupants through installation and use of service systems exert significant direct and indirect impacts on the environment. A developed area has a profound impact on the natural environment, economy, health and productivity of building occupants through its associated characteristics (U.S. Green Building Council, 2010). According to the U.S. Environmental Protection Agency (2010), in the United States alone, buildings account for about 72% of electricity consumption, 39% of energy use, 38% of all carbon dioxide (CO_2) emissions, 40% of raw materials use, 30% of waste output (136 million tons annually) and 14% of potable water consumption. Globally, buildings utilize different forms of energy and produce potentially harmful atmospheric emissions. An adequate response to these environmental issues requires an integrated and synergistic approach (Bolin, 2010).

The life cycle of a building shows that its operational stage has a connection with global climate due to the repository of future carbon emissions, because buildings account for about 30% of the threat to global warming (Otegbulu *et al*., 2011). The process of combustion of fuel during the use of generating sets has severe effects on the indoor and outdoor environment. The increase in human activity, particularly in the burning of fossil fuels in recent times, keeps increasing the concentration of greenhouse gases (GHG) and thus raising the earth's temperature. According to Ewings (2008) and Knight and Whitmarsh (2008), the earth's average surface temperature is now within the range of 0.6 to 0.8 ^oC and the projected increase between 1990 and 2100 is put at 1.4 to 5.8 ^oC. Carbon dioxide (CO_2), an important greenhouse gas from fossil fuel combustion, is significantly increasing the earth's temperature to give rise to a state of global warming. The Intergovernmental Panel on Climate Change set up in 1988 revealed a relationship between combustion of fuels and impending threats to climate change through discharges of emissions (Otegbulu *et al*., 2011). The effects of global warming produce extreme weather conditions and, consequently – abnormal changes in the global climate. Osuntogun and Koku (2007) indicated that exposure to emissions during the combustion of fuel through the use of generating sets and other human activities above approved limits can lead to traces of high blood pressure, shortness of breath and abnormal emotional behaviour, among others.

Nigeria is a rich-resource country endowed with enormous amount of both renewable and non-renewable primary energy resources. Statistical data ranked Nigeria as the 6th largest oil producer in the world. In addition to the oil wealth, the country has an estimated 182 trillion cubic feet of proven natural gas reserves, the seventh largest reserves in the world (EIA, 2007; ECN, 2005). Throughout the world, electricity is the most widely used and desirable form of energy. It is a basic requirement for economic development and adequate standard of living. As the country's population grows and its economy expands, the demand for electric energy increases, as well. If this demand is not met adequately, a shortage of energy supply occurs, and this can really assume crisis proportions. According to Chigbue (2006), electric power as the major component in the requirements for effective industrialization and its development is grossly inadequate in Nigeria. At present, the power industry in Nigeria is beset by major difficulties in the core areas of operation, generation, transmission, distribution and marketing (Idigbe and Onohaebi, 2009).

In Nigeria, electricity demand is mainly from residential, commercial and industrial sectors. Consumption has increased from less than 2,000 GWh in 1970 to about 11,044 GWh in 1990, representing an annual growth rate of 9% within the period and to 14,325 GWh in 1998 (Subair and Oke, 1998). Poor electricity supply is perhaps the greatest infrastructural problem confronting the business sector in the country. A typical Nigerian firm experiences power failure or voltage fluctuations about seven times per week, each lasting for about two hours, without the benefit of prior warning. As a result of this fundamental problem, households, businesses and industrial premises rely on their self-produced electricity from generators that have attendant operating and capital costs (Idiata *et al.,* 2010; Awofeso, 2011).

In an attempt to address problems of electricity supply, building occupants across the globe have been adopting the principle of off-grid power supplies, microgeneration of power, through the use of micro hydro plants, wind power plants, biogas plants, generators and photovoltaic (PV) plants (Harrison, 2008). In Nigeria, many people, companies and institutions supplement the grid system with their own generators. This is noticed in the use of different types of generators; petrol or diesel powered generators by occupants of different types of buildings and well over 90% of businesses in Nigeria have generators (World Bank, 2005). Nigeria has the highest concentrations of generators globally, despite its rich energy source and more than 60 million people own generators to provide electricity for homes and businesses (British Broadcasting Corporation Africa, 2013). The impacts of the various types of generators used by occupants of buildings are enormous on environmental quality and people's health. This has elicited major concerns among environmentalists and other players with respect to developed areas (Obadote, 2009). The use of generators is very common in most parts of Nigeria, and most small-scale businesses that could be essentially noiseless, in fact produce heavy noise pollution from generators (Akande and Ologe, 2001). This has resulted in the exposure of building users to a number of hazards associated with the use of generators in their buildings. Common hazards are air, soil, noise and water pollution. These hazards not only affect users of the generators, but also affect people living in the neighborhood (World Health Organization, 2004).

In an effort to consider the functioning state of generating sets and the likely impacts that they can have on the environment, a few studies have been conducted on generators used in buildings in Nigeria and, especially, in the study area. However, studies of Otasowie and Omoruyi (2010), Komolafe (2011), Ahmed and Abubakar (2012), Orumu and Ephraim (2013), Ana *et al*., (2014), Sonibare *et al*., (2014) did not focus on the likely indoor and outdoor effects of carbon monoxide emissions through comparison with established standards that are associated with the use of generators in both residential and commercial building; hence the need for such a study. Consequently, the specific objective of the study was to assess outdoor and indoor carbon monoxide levels of generators used and their impact on the environment and building occupants.

2. Research methodology

The sample frame for the study was made up of residential and commercial buildings that existed in the selected five local governments of the study area, Ibadan Metropolis, which were occupied for residential and commercial purposes and where generating sets were used. Ibadan is the capital of Oyo State in the southwestern part of Nigeria (Ayeni, 1994). Ibadan is an urban centre located in the humid southwest of Nigeria and it is the capital city of Oyo State. The geographical location of Ibadan falls between coordinates 7° 22' 47" North of the Equator and 3° 53' 0" East of the Greenwich Meridian. The entire area of Ibadan is largely well-drained, though many of its rivers are seasonal. Developed land increased from only 100 ha in 1830 to 12.5 km^2 in 1931, 30 km^2 in 1963, 112 km^2 in 1973, 136 km^2 in 1981 and 214 km^2 in 1988 (Mabogunje, 1968). It is therefore capable of reflecting practices and attributes of the region. Its estimated population of 2,559,853 by the 2006 population census places the city in the category of metropolitan urban centres (FGN, 2009). The study concentrated on the five local government areas that compose Ibadan Metropolis namely: Ibadan North, Ibadan North East, Ibadan North West, Ibadan South East and Ibadan South West. The local governments have a population of 1,343,147 (FGN, 2009) and the other six local governments that make up Ibadan Land were left out. The choice of the local governments was due to the fact that the research is urban-based and focused on the sustainability of generating sets used by residents/occupants of buildings that were within the metropolis of the study area.

A reconnaissance survey was carried out. The study area was divided into a list of different residential/political wards, determined and used for the purpose of the 2011 general elections by the (Oyo State Independent Electoral Commission, 2013). The multi-stage sampling technique was employed for the study. The first stage involved delineation of residential areas in Ibadan Metropolis into different zones based on age and other criteria. The technique of delineating residential areas in Nigeria involves the use of historical and physical attributes. It takes into consideration the period of the emergence of the city or a section of the city, housing characteristics, environmental qualities and population per square kilometre (density) among others (Afon, 2008; Wojuade, 2012; Adigun 2013). Faniran (2012), among other authors, identified three (3) residential zones in Ibadan. These are: core, transition and suburban residential zones and they were thus adopted for this study. The stratification made the heterogeneous nature of the study population reduced into residential/political wards of similar and homogeneous features.

The objective approach used during the course of this study involved measurement of carbon monoxide levels of generating sets (0.6 kVA to 3.8 kVA) in buildings purposively selected in the study area. The likely effects of the use of generating sets on the environment were evaluated through the use of a digital carbon monoxide meter to take measurement of carbon monoxide levels generated before and during the use of the generators at daytime both indoor and outdoor in line with the provisions set by OSHA (2004) and NESREA (2011). The HT-1000 digital LCD carbon monoxide meter was used to take measurements of the emissions of CO that can affect indoor air quality of both external and indoor spaces of the buildings. The emission of carbon monoxide was singled out to be measured amongst other emissions likely to be discharged during the use of generating because most cases of suffocation that led to death of people have been traced to it (Neil and Jenette, 2005). The carbon monoxide meter has the following specifications: measurement range of 0-1000 ppm, measurement resolution of 1 ppm, an accuracy of ±5% or ±10 ppm and operating temperature of 0 to 50 ^{o}C. The measurements were taken after 180 seconds calibration in line with the provisions set by OSHA (2004).

2.1 Air pollution measurement

The quality of air impaired by the emissions of carbon monoxide associated with the use of generating sets were measured with a digital gas meter at daytime at the points of locations of the generators in line with the provisions of OSHA (2004). Five (5) houses were purposively selected in each residential density of the local governments in the study area. This indicates selection of twenty-five (25) residential buildings in each zone and seventy-five (75) residential buildings in the entire study area, respectively (Table 1). Measurements of carbon monoxide levels in the selected buildings were carried out before and during the use of the generators both indoor and at distances outdoor. Similarly, five (5) commercial buildings were also purposively selected in each of the residential densities of the local governments in the study area for the measurement of carbon monoxide emission. This also indicates selection of twenty-five (25) commercial buildings and seventy-five (75) commercial buildings in each zone and in the study area, respectively (Table 1). Carbon monoxide emission levels of the generators were taken to assess their contributory impact/effect on the environment and users of the buildings sampled.

(a) Outdoor CO emission level before and during use of generators

The measurements of outdoor carbon monoxide level either before or during the use of generators were taken at three points; 0, 2 and 4m, respectively, from the external walls of the buildings sampled in the study area. The mean value of the readings in each building was determined. 0m was the point of location of the generator by the external wall of the buildings sampled. Hence, three (3) measurements of outdoor carbon monoxide before and during use of generators, respectively, were taken at the points of locations of generators from external walls of the buildings selected.

(b) Indoor CO emission level before and during use of generators

Three (3) measurements of indoor carbon monoxide level before and during the use of generators, respectively, were taken at a point (actively useable internal space) in each of the buildings selected in each residential density of the study area. The measurements were taken at a least distance of 1m from walls or other major reflecting surfaces, 1.2-1.5m above floor level and 1.5m from windows. The mean value of the measurements in each building was determined. This helped to assess contributory effect and impact of the use of generating sets on the indoor carbon monoxide level in the buildings. Figure 1 shows the diagrammatic representation of the measurement of carbon monoxide emissions both outdoor and indoor.

The values of the measurements of carbon monoxide taken in the buildings sampled with the aid of a digital gas analyser were analysed statistically and also compared with the limits set by the National Environmental Standards and Regulations Enforcement Agency (NESREA, 2011) and World Health Organisation (WHO, 2010). This also helped to assess probable effects of carbon monoxide emission discharged during the use of generating sets on the well-being of the buildings' occupants and overall sustainability of the environment. Thereafter, both descriptive and inferential statistics were used in analysing the data collected for this study and the analytical techniques used depended on the forms and normality of the data collected.

Table 1. Schedule of residential and commercial buildings sampled in the study area for the measurement of carbon emission levels

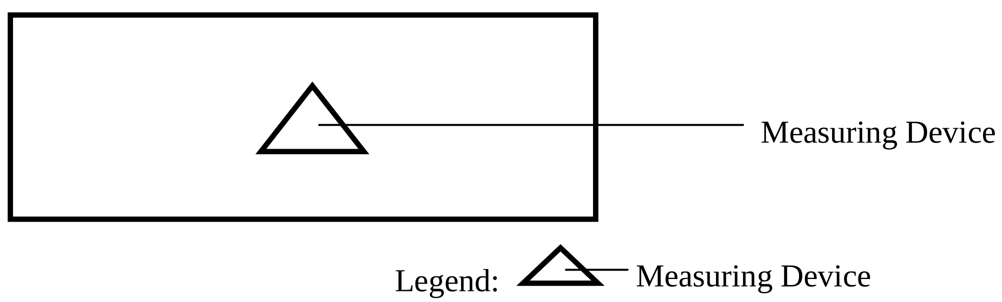
S/N	Study area	Core zone	Transition zone	Suburban zone	Total
1	Ibadan North	5Res	5Res	5Res	15Res
		5Com	5Com	5Com	15Com
2	Ibadan North East	5Res	5Res	5Res	15Res
		5Com	5Com	5Com	15Com
3	Ibadan North	5Res	5Res	5Res	15Res

	West	5Com	5Com	5Com	15Com
4	Ibadan South	5Res	5Res	5Res	15Res
	East	5Com	5Com	5Com	15Com
5	Ibadan South	5Res	5Res	5Res	15Res
	West	5Com	5Com	5Com	15Com
Total		25Res	25Res	25Res	75Res
		25Com	25Com	25Com	75Com

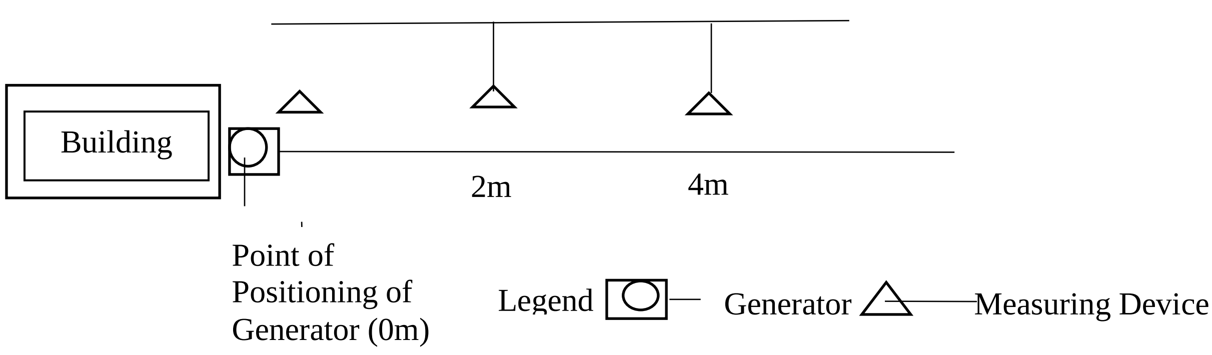
Res: Residential Building Com: Commercial Building

Source: Author's own elaboration.

Figure 1. Diagrammatic views of sections of the measurement of carbon monoxide emission levels outdoor and indoor (actively used internal space in the building)



Indoor measurement of carbon monoxide emission



Outdoor measurement of carbon monoxide emission

Source: Author's own elaboration.

3. Results and Discussions

3.1 Outdoor carbon monoxide levels of generators in the residential and commercial buildings

The measurements of outdoor carbon monoxide levels before and during use of generators in the residential buildings sampled across zones of the study area shown in Tables 2 to 4 revealed that irrespective of the zone where residential buildings sampled were located, outdoor carbon monoxide levels before the use of generators maintained a fluctuating pattern in the readings at different points of the measurements. This could be due to the effect of intensity and air velocity which could impact the increase or decrease of carbon monoxide readings at different points of measurement. It was found that at the point of positioning of generators beside the external walls, outdoor carbon monoxide levels in residential buildings in the core zone (4.3-11.6 ppm) were comparably highest before use of the generators and the least in suburban zone (1.0-4.6 ppm). This was observed to be due to the cleanliness, serenity and house-keeping practices maintained by respondents in the respective zone. Also, during the use of generators, carbon monoxide levels were comparably highest in residential buildings in the core zone with 385.0- 473.3 ppm, transition zone (385.3-423.7 ppm) and suburban zone (308.3-411.3 ppm), respectively. However, at 2 and 4m points of measurement from the locations of the generators by the external walls during their use, outdoor carbon monoxide levels in the transition zone was the lowest, with 245.7 ppm and in suburban zone (115.3 ppm), respectively. This was found to be related to operational performance of the generating sets used in the residential buildings across the zones. Similarly, the outdoor carbon monoxide measurements were significantly highest (477.7 ppm) at the reference point, external wall of buildings and the lowest (75.6 ppm) at the 4m distance away from the external walls of the buildings.

The degree of variation of outdoor carbon monoxide levels taken in the sampled residential buildings showed that the mean levels of outdoor carbon monoxide before or during use of the generators were comparably highest in residential buildings in the core zone (7.3 ppm, 415.40 ppm). This was discovered to be due to the efficiency of the generators and house-keeping practices of the respondents. Largely, in all the measurements taken in residential buildings across the zones of the study area, carbon monoxide levels were comparably highest at the reference point (by the external walls for the positioning of the generators) followed by the readings taken at 2 and 4m, respectively.

The trend analysis carried out on the rate of decrease in outdoor carbon monoxide measurements recorded in the residential buildings sampled during use of generating sets showed that the percentage decrease in the values of outdoor carbon monoxide measured from the external walls of the buildings to the 2m point of measurement was 47.88%. It also showed that there was a 51.29% decrease from 2 to 4m point of measurement and a 74.06% decrease was obtained at the 4m point of measurement from the external walls of the residential buildings.

Table 2. Outdoor carbon monoxide levels before and during use of generators in residential buildings in the core zone

Outdoor CO level (ppm) before and during use of generators at different points							
	Residential buildings	0m		2m		4m	
L.G.A		Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)
IBN	1	10.3	429.3	9.0	275.3	9.0	153.3
	2	8.3	399.3	7.6	233.6	6.7	183.7
	3	9.6	405.6	9.3	236.6	9.3	175.3
	4	11.3	432.6	11.3	189.7	9.0	111.0
	5	8.3	422.3	8.0	238.0	8.0	143.0
IBNE	6	6.6	385.0	5.3	215.3	5.0	121.3
	7	8.3	477.3	7.6	174.0	6.6	124.3
	8	10.0	413.0	9.3	243.3	9.3	99.3
	9	6.6	435.3	7.0	285.3	7.0	123.7
	10	5.3	426.6	4.7	216.6	4.0	111.7
IBNW	11	4.6	406.7	3.6	233.3	3.0	160.3
	12	7.6	425.3	6.3	198.7	6.3	97.3
	13	5.3	426.6	4.7	231.3	4.7	134.3
	14	6.7	393.3	6.7	151.7	6.7	98.3
	15	5.3	405.3	5.3	174.6	4.7	83.0
IBSE	16	4.7	385.6	3.7	196.7	3.7	85.3
	17	6.7	420.3	6.0	273.0	6.0	121.6
	18	5.0	453.3	4.7	253.3	4.7	115.3
	19	8.6	422.6	7.7	247.7	7.7	123.0
	20	6.6	397.3	6.0	194.3	6.0	93.3
IBSW	21	4.3	402.3	4.7	241.6	4.7	89.3
	22	5.3	398.3	5.0	181.3	5.3	75.6
	23	8.3	411.3	8.6	228.6	7.3	100.3
	24	7.3	390.6	6.7	193.6	6.7	87.6
	25	11.6	424.3	9.3	275.1	7.3	135.3

* 0 m = Point of measurement from external wall of building
Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West
Source: Author's own elaboration.

Table 3. Outdoor carbon monoxide levels before and during use of generators in residential buildings in the transition zone

Outdoor CO level (ppm) before and during use of generators at different points							
L.G.A.	Residential buildings	0m		2m		4m	
		Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)
IBN	1	5.3	415.3	4.0	237.3	4.0	125.7
	2	6.7	405.7	4.3	225.0	4.3	103.6
	3	5.3	398.3	5.3	143.7	4.0	89.3
	4	3.3	406.6	3.3	196.7	3.0	105.7
	5	6.7	415.6	5.6	183.6	4.3	93.3
IBNE	6	7.7	400.3	6.7	221.3	6.7	108.0
	7	6.3	391.3	4.3	142.3	4.3	83.7
	8	6.7	415.6	5.7	227.0	4.3	123.6
	9	10.6	423.7	9.0	235.7	9.0	106.3
	10	6.3	411.3	6.3	229.6	5.6	99.7
IBNW	11	7.3	405.7	7.3	211.3	7.3	89.6
	12	5.6	421.3	5.6	230.7	4.3	125.3
	13	7.3	388.3	7.3	195.3	7.3	73.6
	14	3.3	405.3	2.7	209.3	2.7	97.6
	15	5.7	390.3	5.7	185.3	5.7	74.7
IBSE	16	3.3	413.3	3.3	241.0	3.3	88.3
	17	4.3	390.6	4.3	173.3	3.3	93.6
	18	3.3	411.3	3.3	245.7	2.6	111.3
	19	5.0	385.3	5.0	173.3	4.3	76.3
	20	4.3	405.6	4.3	233.3	3.3	122.7
IBSW	21	3.3	402.3	3.3	227.6	3.3	109.3
	22	2.6	385.3	2.6	193.3	2.0	76.7
	23	1.0	392.3	1.0	184.0	1.0	85.6
	24	3.3	400.6	3.0	225.7	2.6	111.3
	25	2.6	390.3	2.6	173.6	2.0	98.6

* 0 m = Point of measurement from external wall of building
Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West
Source: Author's own elaboration.

Table 4. Outdoor carbon monoxide levels before and during use of generators in residential buildings in the suburban zone

Outdoor CO level (ppm) before and during use of generators at different points							
L.G.A.	Residential buildings	0m		2m		4m	
		Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)
IBN	1	1.3	403.3	1.0	233.3	1.0	105.3
	2	2.3	388.7	2.0	175.0	1.3	97.6
	3	2.3	404.3	2.0	211.7	2.0	98.3
	4	3.0	411.6	3.3	225.3	2.0	85.6
	5	4.6	308.3	3.0	165.6	2.3	79.3
IBNE	6	4.0	368.3	3.3	193.0	3.0	97.0
	7	3.0	406.6	2.3	227.3	2.0	105.7
	8	3.3	399.3	3.3	147.6	3.0	87.6
	9	1.3	400.6	1.0	218.6	1.0	100.3
	10	4.6	388.7	4.6	133.3	3.3	75.6
IBNW	11	2.0	405.3	2.3	175.3	2.0	82.3
	12	2.3	385.6	2.3	163.6	2.0	93.3
	13	3.0	325.7	3.3	176.6	2.3	75.7
	14	3.3	408.3	2.3	242.3	2.0	101.3
	15	3.0	411.3	3.0	198.3	2.3	86.0
IBSE	16	2.6	323.3	2.0	200.3	2.0	73.6
	17	1.0	345.6	1.0	215.3	1.0	79.3
	18	3.0	411.3	2.3	227.6	2.0	74.3
	19	4.6	337.6	4.3	175.3	4.0	69.7
	20	1.3	405.3	1.0	238.3	1.0	95.3
IBSW	21	3.0	400.6	3.3	225.6	3.0	103.0
	22	2.7	385.3	2.0	153.6	2.0	85.3
	23	2.3	411.3	2.3	227.0	2.0	115.3
	24	3.3	382.3	3.0	147.3	2.3	68.3
	25	3.0	403.6	2.3	253.6	2.0	81.3

* 0 m = Point of measurement from external wall of building
Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West
Source: Author's own elaboration.

The measurements of outdoor carbon monoxide levels taken in the commercial buildings were similar to those obtained in the residential ones. Tables 5 to 7 demonstrate that outdoor carbon monoxide levels were the highest during use of the generators (473.3 ppm) when positioned by the external walls of the buildings in the core zone and the lowest in the suburban zone (413.3 ppm). This was due to the house-keeping practices and operational performance of the generating sets used in those buildings. Apart from this, Tables 5 to 7 show that carbon monoxide levels decreased with distance from the external walls of the buildings as also found in residential buildings. The degree of variation in the outdoor carbon monoxide levels taken in the sampled commercial buildings showed that the mean levels of outdoor noise were significantly higher in the buildings located in the core zone than in the other areas under analysis. In all the measurements taken, it was found that outdoor carbon monoxide levels were also comparatively higher when the measurements were taken at the external walls followed by the measurements taken at 2 and 4m, respectively.

The trend analysis carried out on the rate of decrease of outdoor carbon monoxide measurements in the commercial buildings sampled during use of generating sets in the study area showed that the percentage decrease in the values of outdoor carbon monoxide measured from the external walls of commercial buildings to the 2m point of measurement was 53.06%. It further showed that there was a 50.47% decrease from 2 to 4m point of measurement and a 76.78% decrease was obtained at the 4m point of measurement from the external walls of the commercial buildings.

Table 5. Outdoor carbon monoxide levels before and during use of generators in commercial buildings in the core zone

Outdoor CO level (ppm) before and during use of generators at different points							
L.G.A.	Commercial buildings	0m		2m		4m	
		Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)
IBN	1	13.3	411.3	13.0	225.3	13.0	98.7
	2	19	399.3	17.0	147.6	16.0	84.6
	3	16.6	403.6	16.6	231.7	16.6	118.3
	4	24.3	411.3	24.0	223.0	23.3	109.3
	5	33.6	425.6	33.6	271.3	33.0	99.7
IBNE	6	9.7	411.3	9.0	225.3	9.0	88.3
	7	13.6	408.6	13.0	219.7	13.0	97.9
	8	9.3	388.6	9.3	148.3	9.3	110.3
	9	5.6	422.3	5.6	225.0	5.0	87.6
	10	9.7	416.3	9.0	218.3	8.0	104.3
IBNW	11	8.7	408.3	8.7	225.7	8.0	96.9
	12	16.3	411.6	16.0	203.0	15.0	89.3
	13	22.3	412.3	22.0	198.7	22.0	101.3

	14	17.7	396.7	17.7	144.3	17.3	98.3
	15	11.3	408.6	12.0	218.6	12.0	88.7
IBSE	16	16.6	388.7	16.0	139.3	15.0	100.0
	17	22.3	411.3	20.0	203.6	20.3	93.7
	18	23.7	401.7	23.0	142.7	23.0	96.3
	19	15.3	411.3	15.3	208.3	15.0	95.3
	20	11.3	326.3	11.3	133.6	10.3	88.6
IBSW	21	13.3	406.3	13.0	209.3	11.3	94.7
	22	15.3	399.3	15.0	147.0	14.0	100.3
	23	16.6	412.6	16.6	222.3	15.0	83.7
	24	18.3	396.7	18.0	141.0	17.3	99.6
	25	23.6	412.3	23.0	195.3	22.0	87.6

* 0 m = Point of measurement from external wall of building
Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West
Source: Author's own elaboration.

Table 6. Outdoor carbon monoxide levels before and during use of generators in commercial buildings in the transition zone

Outdoor CO level (ppm) before and during use of generators at different points							
L.G.A.	Commercial buildings	0m		2m		4m	
		Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)
IBN	1	7.3	372.3	7.0	153.3	6.7	83.6
	2	9.7	411.6	9.0	221.6	9.0	98.3
	3	11.3	325.3	10.3	172.3	10.3	101.3
	4	10.0	405.7	9.0	223.7	8.0	87.6
	5	6.7	388.6	6.7	113.6	6.0	79.3
IBNE	6	9.3	411.3	8.3	208.6	8.0	102.3
	7	10.3	408.6	10.0	238.7	9.0	93.7
	8	7.3	329.3	7.3	147.3	6.0	87.6
	9	9.7	413.7	9.0	165.3	9.0	91.3
	10	6.3	363.6	5.0	135.7	5.0	89.6
IBNW	11	6.0	423.6	6.0	218.6	6.0	100.3
	12	12.3	405.6	11.0	165.3	11.0	77.6
	13	13.7	393.3	13.0	141.6	12.0	94.3
	14	9.0	412.3	9.7	182.3	9.0	93.7
	15	13.3	323.7	13.0	128.6	12.0	88.6
IBSE	16	6.3	363.6	6.3	131.3	6.0	77.6
	17	5.0	324.3	4.0	223.7	4.0	93.3
	18	6.0	412.3	5.7	219.6	5.3	100.3
	19	7.7	388.7	7.0	163.3	6.0	95.0

	20	5.0	365.3	4.0	153.0	3.0	87.6
IBSW	21	6.3	403.7	6.0	221.7	6.0	88.3
	22	5.7	363.6	5.0	143.6	4.0	76.6
	23	4.6	325.3	4.0	165.0	3.0	85.3
	24	4.0	400.7	3.0	158.7	2.7	91.3
	25	3.3	388.3	3.0	123.7	3.0	83.3

* 0 m = Point of measurement from the external wall of a building
Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West
Source: Author's own elaboration.

Table 7. Outdoor carbon monoxide levels before and during use of generators in commercial buildings in the suburban zone

Outdoor CO level (ppm) before and during use of generators at different points							
L.G.A.	Commercial buildings	0m		2m		4m	
		Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)
IBN	1	8.3	385.3	8.0	135.6	7.3	100.3
	2	7.6	411.6	7.6	241.3	7.0	94.6
	3	8.3	325.3	7.6	123.6	6.0	83.7
	4	5.6	327.6	5.0	142.3	4.3	77.7
	5	6.7	400.3	6.3	203.7	6.0	91.3
IBNE	6	8.3	363.7	8.0	133.3	8.0	79.3
	7	6.0	320.3	5.0	113.6	4.3	82.0
	8	9.3	337.6	9.3	124.3	8.0	76.6
	9	5.3	403.6	5.0	223.6	4.7	85.7
	10	8.0	339.3	7.3	146.7	7.0	80.6
IBNW	11	7.3	422.3	7.0	208.3	6.0	83.6
	12	11.3	411.9	11.3	225.6	11.0	77.3
	13	6.7	425.3	6.0	235.6	5.3	92.0
	14	6.3	420.6	6.3	197.3	5.0	76.3
	15	5.6	383.7	6.0	153.7	5.3	79.6
IBSE	16	4.7	305.3	4.0	128.3	3.3	80.0
	17	3.3	413.6	3.0	235.3	2.7	91.3
	18	9.0	412.3	8.0	219.6	7.0	84.6
	19	6.3	415.7	6.0	195.3	5.0	78.3
	20	6.6	376.3	6.6	201.3	6.0	85.6
IBSW	21	4.3	308.6	4.0	143.6	3.3	74.3
	22	5.0	313.6	5.3	120.0	3.7	76.6
	23	4.7	343.7	4.0	167.6	3.7	80.3
	24	8.3	411.3	8.0	218.3	7.3	82.3

	25	6.6	357.3	6.0	170.3	5.3	79.6

* 0 m = Point of measurement from external wall of building
Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West
Source: Author's own elaboration.

3.2 Indoor carbon monoxide levels of generators in the residential and commercial buildings

Table 8 shows the indoor carbon monoxide levels before and during use of the generators in the residential buildings. It was revealed that prior their usage, the indoor carbon monoxide levels were the lowest in the buildings (0.6 ppm) located in the suburban zone and the highest in those (8.0 ppm) in the core zone. During the use of generators, indoor carbon monoxide level was the lowest in the suburban zone (3.0 ppm) and also the highest in the buildings in the core zone (28.6 ppm). This was attributed to the distances of positioning of the generators, house-keeping practices adopted, typology of buildings and profile of the respondents in the buildings sampled. The mean deviation of indoor carbon monoxide levels before use of the generators was 4.04 ppm, 1.95 ppm and during use of the generators – 13.71 ppm and 5.07 ppm in the core and suburban zones, respectively.

The differences in the rate of change of indoor carbon monoxide levels before and during the use of generators in the residential buildings sampled were carried out through the use of trend analysis. The analysis showed that the percentage increase in the values of indoor carbon monoxide in residential buildings in the core, transition and suburban zones before and during use of the generators was 269.78%, 200.38% and 220.90%, respectively. It further indicated that in all the residential buildings sampled in the study area, the percentage increase in the values of indoor carbon monoxide before and during use of generators was 230.35%. This indicates the range of percentage increase in the indoor carbon monoxide levels that occupants of the residential buildings in the study area could be exposed to.

Table 8. Indoor carbon monoxide levels before and during use of generators in residential buildings

		Core zone		Transition zone		Suburban zone	
L.G.A	Bldgs.	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)

IBN	1	5.6	22.3	4.0	13.6`	1.3	3.0
	2	3.0	15.3	3.0	11.3	2.0	3.3
	3	6.3	24.6	3.3	9.6	1.6	5.0
	4	3.3	16.7	2.0	6.0	2.3	5.7
	5	4.6	11.3	2.6	8.7	3.0	6.0
IBNE	6	5.0	10.6	6.0	10.3	3.3	8.0
	7	5.6	15.3	4.0	11.0	2.0	6.0
	8	4.0	11.3	5.0	9.0	1.3	3.6
	9	3.0	18.6	6.0	10.3	0.6	5.0
	10	2.0	6.6	3.3	9.6	3.0	7.6
IBNW	11	0.6	5.0	3.0	10.0	1.3	3.0
	12	3.6	8.7	3.3	5.7	2.0	5.0
	13	1.3	8.0	4.0	8.3	2.0	6.0
	14	5.0	15.7	2.0	6.0	2.3	6.6
	15	3.0	11.5	3.0	10.3	2.3	5.3
IBSE	16	2.6	8.3	2.3	5.3	1.3	4.0
	17	3.6	9.7	3.0	7.3	0.6	6.3
	18	4.6	11.7	2.0	6.6	2.6	3.0
	19	5.7	18.6	4.0	8.3	3.0	6.0
	20	4.6	12.6	3.0	6.0	0.6	3.0
IBSW	21	2.0	7.0	1.3	6.0	1.3	5.0
	22	3.0	8.6	2.3	5.3	2.0	6.0
	23	5.0	14.0	0.6	5.0	1.3	5.0
	24	6.0	22.3	2.0	6.0	3.0	7.6
	25	8.0	28.6	1.3	5.0	3.0	5.0

Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West
Source: Author's own elaboration.

Table 9 shows that the indoor carbon monoxide levels both before and during the use of generators in commercial buildings were comparably higher than the measurements taken in the residential buildings. This could be due to the level of commercial activities close to the buildings sampled. Table 9 further reveals that in commercial buildings, the indoor carbon monoxide value of 4.0 ppm in the core zone recorded before the use of generators was higher than that of 2.3 ppm and 2.0 ppm obtained in transition and suburban zones, respectively. This was due to the volume of commercial activities going on in the buildings in each zone and operational characteristics of the generating sets used by the occupants. However, during the use of generators, the range of indoor carbon monoxide levels in core, transition and suburban zones were: 20.0-98.0 ppm, 14.0- 56.7 ppm and 18.3-45.3 ppm, respectively. The performance, closer distance of positioning of the generators to the external walls of commercial buildings than that of residential buildings and house-keeping practices maintained influenced this trend.

The differential deviation in the mean values of indoor carbon monoxide levels in commercial buildings before the use of generators in the core, transition and suburban zones reached the values of 8.33 ppm, 4.02 ppm and 3.82 ppm, respectively; whereas during the use of generators they were: 50.61 ppm, 32.90 ppm and 33.36 ppm in core, transition and suburban zones, respectively. It was also discovered that the house-keeping practices adopted, serenity, typology of buildings and the profile of the occupants were responsible for the significantly higher values of the outdoor and indoor carbon monoxide levels in buildings situated in the core zone than in those located in the other ones (Tables 2 to 9). The trend analysis showed that the rate of change in the percentage increase in the values of indoor carbon monoxide in commercial buildings in the core, transition and suburban zones before and during the use of generator was 614.52%, 786.31% and 882.44%, respectively. It also indicated that in all the commercial buildings sampled across the zones, the percentage increase was 761.09% and it was thrice that of the residential buildings.

Table 9. Indoor carbon monoxide levels before and during use of generators in commercial buildings

		Core zone		Transition zone		Suburban zone	
L.G.A.	Bldgs.	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)	Before use (ppm)	During use (ppm)
IBN	1	11.0	67.3	4.0	14.0	3.3	32.3
	2	17.0	56.0	3.0	23.3	6.0	31.6
	3	8.0	43.3	6.0	45.3	5.6	42.7
	4	10.6	53.6	3.6	56.7	4.6	31.3
	5	11.3	65.3	4.3	35.3	4.3	43.6
IBNE	6	9.0	42.3	3.7	15.0	5.0	35.0
	7	8.3	32.0	2.7	23.6	4.7	28.3
	8	6.0	20.0	5.0	35.3	3.6	42.3
	9	4.0	54.0	6.0	25.0	4.0	31.3
	10	5.6	68.0	3.0	31.0	3.3	26.0
IBNW	11	3.3	74.3	4.3	25.6	5.3	43.3
	12	4.0	63.0	7.0	43.6	3.0	31.3
	13	9.0	23.0	6.7	30.0	3.3	45.3
	14	5.0	43.0	6.0	44.3	2.6	27.3

	15	6.0	23.0	4.6	35.0	3.0	45.0
IBSE	16	11.0	75.6	3.0	45.2	2.0	36.7
	17	8.0	35.0	2.6	18.0	2.6	26.7
	18	9.0	32.0	3.0	34.0	7.0	45.3
	19	7.3	45.3	4.3	47.6	5.3	32.3
	20	8.3	53.3	2.6	28.3	3.3	25.0
IBSW	21	11.0	53.3	3.0	28.3	2.7	27.0
	22	6.3	65.3	2.3	18.0	2.0	33.3
	23	8.3	98.0	4.7	26.0	4.0	28.0
	24	10.0	45.3	3.3	45.3	2.6	18.3
	25	11.3	33.0	2.3	48.3	3.0	25.3

Legend: LGA = Local Government Area; IBN = Ibadan North; IBNE = Ibadan North East; IBNW = Ibadan North West; IBSE = Ibadan South East; IBSW= Ibadan South West

Source: Author's own elaboration

3.3 Comparison of the carbon monoxide levels in the buildings with the statutory limits

At the next stage, an assessment was made of the impact of the use of generators in the study area by comparing the values of carbon monoxide measured both outdoor and indoor, before and during the use of generators in residential and commercial buildings in the area under analysis. The One Sample T-test statistical technique was used to analyse the impact of its usage through the level of deviation from the limits set by the NESREA (2011) and the WHO (2010) in residential and commercial buildings, respectively.

The results of the analysis as contained in Table 10 show that in the residential buildings, the T-test indicated that mean values of outdoor carbon monoxide before and during the use were 5.10 ppm and 401.35 ppm, while the mean difference in outdoor carbon monoxide before the use was -4.89 ppm and 391.35 ppm during the use of generators from the test value of 10 ppm. It further shows that at 95% confidence interval, the upper difference between the carbon monoxide limit set by NESREA (2011), WHO (2010) and the values measured was -4.30 and 397.27, respectively for before and during the use of generators. The mean values of the outdoor carbon monoxide before and during the use were 5.10 ppm and 401.35 ppm, respectively. The relationship is as follows: $t = -16.723$, $p < 0.001$ – before the use and $t = 131.789$, $p < 0.001$ – during the use).

Also, the result of the T-test shows that the mean difference in the indoor carbon monoxide before and during use were -6.97 ppm and -1.06 ppm at before and during use, while at 95% confidence interval, the upper difference from the limit of NESREA (2011) and the values of carbon monoxide measured were -6.6152 and 0.1412 before and during the use of generators, respectively (Table 10). The mean values before and during the use of generators were 3.02 ppm and 8.93 ppm. The relationship is given as: $t = -38.260$, $p < 0.001$ – before the use and $t = -1.760$, $p < 0.001$ – during the use). The results obtained from the analysis reveals that carbon monoxide produced by generators is more impactful on the environment and would thus, expose building occupants to severe interrelated cardiovascular and other physiological effects because of the significant difference of the outdoor or indoor carbon monoxide level measured during the use and before the use of generators in the buildings. The findings of this study substantiate past works of World Bank (2004) and Osuntogun and Koku (2007) that exposures of people to carbon monoxide could cause and lead to cases of high blood pressure, shortness of breath, emotional behaviour amongst others.

Table 10. Comparison of the outdoor carbon monoxide levels in the residential buildings with the NESREA standards

Comparison of outdoor CO levels in the residential buildings						
One –Sample Test						
Test Value = 10						
Variables	T	Df	Sig (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Outdoor CO Before Use	-16.723	74	.000	-4.89067	-5.4734	-4.3080
Outdoor CO During Use	131.789	74	.000	391.35733	385.4403	397.2743
One-Sample Statistics						
	N	Mean	Std. deviation	Std. error mean		
Outdoor CO Before Use	75	5.1093	2.53266	.29245		
Outdoor CO During Use	75	401.3573	25.71718	2.96956		
Test value of NESREA (2011) = 10ppm						

Comparison of the indoor CO levels in the residential buildings

One –Sample Test						
Test Value = 10						
Variables	T	Df	Sig (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Indoor CO Before Use	-38.260	74	.000	-6.97867	-7.3421	-6.6152
Indoor C0 During Use	-1.760	74	.000	-1.06667	-2.2745	-1412
One-Sample Statistics						
	N	Mean	Std. deviation	Std. error mean		
Indoor CO Before Use	75	3.0213	1.57962	.18240		
Indoor CO During Use	75	8.9333	5.24972	.60619		
Test value of NESREA (2011) = 10ppm						

Source: Author's own elaboration.

The results of the T-test in Table 11 reveal that in the commercial buildings, the mean difference in outdoor carbon monoxide before and after the use of generators was 0.34 ppm and 376.16 ppm, respectively. They also show that at 95% confidence interval, the upper difference between the carbon monoxide limit (10 ppm) set by NESREA (2011) and WHO (2010), and the values measured was 1.69 and 384.15 for before and during the use of generators, respectively. The relationship is as follows: $t = 0.503$, $p < 0.001$ – before the use and $t = 93.778$, $p < 0.001$ – during the use).

The T-test carried out also shows that the mean difference in the indoor carbon monoxide for before and during the use of generators were -4.60 ppm and 28.96 ppm, respectively, while at 95% confidence interval, the upper difference set from the limit of NESREA (2011) and the values of carbon monoxide measured were -3.9327 and 32.5883 for before and during the use of generators, respectively (Table 11). The mean values for before and during the use of generators were 5.39 and 38.96 ppm. The relationship is given as: $t = -3.643$, $p < 0.001$ – before the use and $t = 15.910$, $p < 0.001$ – during the use). The results of the analysis equally show the that impact of generators usage is more significant outdoor during their use, and also greater than the impact recorded in the residential buildings.

Table 11. Comparison of the outdoor carbon monoxide levels in the commercial buildings with the NESREA standards

Comparison of outdoor CO levels in the commercial buildings						
One –Sample Test						
Test Value = 10						
Variables	T	Df	Sig (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Outdoor CO Before Use	.503	74	.617	.34133	-1.0110	1.6937
Outdoor CO During Use	93.778	74	.000	376.16000	368.1676	384.1524
One-Sample Statistics						
	N	Mean	Std. deviation	Std. error mean		
Outdoor CO Before Use	75	10.3413	5.87767	.67870		
Outdoor CO During Use	75	386.1600	34.73779	4.01117		
Test value of NESREA (2011) = 10ppm						

Comparison of the indoor CO levels in the commercial buildings						
One –Sample Test						
Test Value = 10						
Variables	T	Df	Sig (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Indoor CO Before Use	-3.643	74	.000	-4.60533	-5.2779	-3.9327
Indoor C0 During Use	15.910	74	.000	28.96133	25.3343	32.5883
One-Sample Statistics						
	N	Mean	Std. deviation	Std. error mean		
Indoor CO Before Use	75	5.3947	2.92334	.33756		

Indoor CO During Use	75	38.9613	15.76416	1.82029		
Test value of NESREA (2011) = 10ppm						

Source: Author's own elaboration

The results of the measurement of carbon monoxide levels both indoor and outdoor associated with the use of generators show anthropogenic implications of their use above the limits set by statutory bodies. The findings of Ana *et al.* (2014) showed that emissions of generators above the limits sets by approved bodies caused lung infections amongst workers that had higher exposure rates. Studies of Neil and Jenette (2005), Liangizhu and Steven (2009), Stanley *et al.* (2011), Canadian Environmental Protection Act (1999) showed that people could be exposed to carbon monoxide levels due to combustion of fuels used in buildings. These past findings are similar to the results of this study which proves that significant amount of carbon monoxide is discharged from various types of generating sets used by the occupants of buildings sampled in the study area.

The Kolmogorov Smirnov Test carried out on the normality of the measurements of carbon monoxide emission levels in the study area is shown in Table 12. The Kolmogorov Sminorv and Shapiro Wilk Tests showed that the data of the carbon monoxide emission levels due to the use of generators in the study area were not normally distributed at $p<0.05$. This was due to the significant difference that existed in the values of measurements taken before and during the use of generators in the buildings sampled. This makes the generator to pose potent hazards to the sustainability of the users and environment. Hence, the null hypothesis is accepted while the null hypothesis is rejected, and thus concluded, that the data significantly deviated from normal distribution.

Kolmogorov Smirnov Test:

H_0: The sample population is not normally distributed
H_I: The sample population is normally distributed

Table 12: Test for normality of data using Kolmogorov Smirnov Test

Tests of normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.

Carbon monoxide	.369	600	.000	.607	600	.000

a. Lilliefors significance correction
Source: Author's own elaboration.

4. Conclusion and recommendations

The study shows that an inadequate quality and quantity of electricity lead to a wide and ubiquitous use of electric power generators by respondents in the study area. The results prove that outdoor and indoor measurements of carbon monoxide emissions levels were the highest in buildings located in the core zone either before or during the use of generating sets. This was found to be directly related to the levels of compliance of the building occupants to house-keeping practices, building typology, physical planning statute, and their socio-economic characteristics. Reduced carbon monoxide levels were measured at distance limits beyond 2m from the external walls of buildings across the zones of the study area during the use of generators. In view of the variation that exists between the emission levels of carbon monoxide due to the use of generating sets in both residential and commercial buildings sampled, it is recommended that there is a need to license sale of generating sets with emission control mechanisms that would be properly tested at the point of manufacturing to guarantee its operational performance so as to conform to ISO 3744 and local codes. The users of generating sets should adopt best house-keeping practices by positioning them in properly built enclosure features (generator house) located away from external walls of their buildings. This will allow conformity to the laws of the National Standards of Environmental Regulation (NESREA).

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Ocena emisji tlenku węgla z generatorów energii elektrycznej stosowanych w budynkach w metropolii Ibadan w Nigerii

Streszczenie

Słaba podaż energii elektrycznej do różnych osad w Nigerii, utrzymująca się przez lata, zmusiła mieszkańców budynków do uzależnienia się i przejścia na generatory prądotwórcze. Badanie to określa poziom tlenku węgla na zewnątrz i wewnątrz, odnoszący się do zastosowania generatorów w budynkach mieszkalnych i komercyjnych oraz ocenia ich wpływ na użytkowników i środowisko. Badanie przeprowadzono w Metropolii Ibadan w Nigerii, która została podzielona na strefy: podstawową, przejściową i podmiejską. W rezultacie pięć (5) budynków mieszkalnych i komercyjnych zostało celowo wybranych w każdej strefie badanego obszaru. Do pomiaru emisji tlenku węgla został wykorzystany Cyfrowy miernik tlenku węgla HT-1000 LCD zgodnie ze standardami NESREA i OSHA. Poziomy emisji tlenku węgla na zewnątrz przed lub podczas korzystania z generatorów zostały pobrane odpowiednio na wysokości 0, 2 i 4 metrów z zewnętrznych ścian budynków, z których pobrano próbki, a odpowiednie pomiary wewnętrzne zostały wykonane wewnętrznie na 1,2-1,5 m nad powierzchnią podłogi. Zebrane dane przeanalizowano za pomocą metod statystycznych, takich jak test t, analiza trendów i test Kołmogorowa Smirnowa. Wyniki pokazują, że wartości zewnętrznych i wewnętrznych pomiarów poziomów emisji tlenku węgla były najwyższe w budynkach w strefie rdzeniowej przed lub podczas korzystania z zespołów prądotwórczych. Obniżone poziomy tlenku węgla podczas korzystania z generatorów uzyskano w granicach odległości przekraczających 2 m od zewnętrznych ścian budynków w strefach badanego obszaru. Ze względu na wykonane pomiary i uzyskane wyniki przekraczające limity określone przez organy ustawowe, a także związane z nimi skutki dla środowiska i mieszkańców budynku, zaleca się, aby użytkownicy generatorów byli zmuszeni do umieszczenia ich w oddalonych od siebie obudowach na zewnętrznych ścianach budynków i że rząd powinien zezwolić tylko na sprzedaż zespołów prądotwórczych z mechanizmami kontroli emisji.

Słowa kluczowe: środowisko, elektryczność, budynki, generatory, emisja tlenku węgla.