UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES (UJEAS)

Research Article

Analysis of air pollution from fossil fuel powered electricity generating set around off-campus student's hostel: consideration of location and number of generators in use

Victor M. Mbachu, Solomon C. Nwigbo, Chisom O. Molokwu, Ruth C. Okereke

Special Issue

A Themed Issue in Honour of Professor Ekedimogu Eugene Nnuka on His retirement.

This themed issue honors Professor Ekedimogu Eugene Nnuka, celebrating his distinguished career upon his retirement. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

Edited by
Chinonso Hubert Achebe PhD.
Christian Emeka Okafor PhD.

UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 3(2), June (2024), 644-659
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Analysis of air pollution from fossil fuel powered electricity generating set around off-campus student's hostel: consideration of location and number of generators in use

Victor M. Mbachu[1]*, Solomon C. Nwigbo[2], Chisom O. Molokwu[1], Ruth C. Okereke [1]
[1]Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[2]Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria
*Corresponding Author's E-mail: *vm.mbachu@unizik.edu.ng

Abstract
Although combustion of fossil fuel has been widely reported to pollute the air and to have hazardous effect on humans and the environment, the students of the study area seem to have this cannot-do-without attitude towards fossil fuel powered electricity generating sets and this has resulted to continuous subscription to this electric power source. The paper attempts to understand the combinatorial effect of the factors affecting the pollution level and how, if possible, same can be minimize within the feasible solution space of proper positioning and optimum number of generators in use. Data were primarily sourced from student's hostels with many of such generating sets, collated and analyzed using multivariate regression technique. The obtained result shows that although the positioning of the generators has significant effect on the air pollution level in the student's hostels, for the case analyzed, the optimum distance away from the generator's house (housing 14 generating sets) is about 35.73 meters for maximum air pollution level of 15 and humidity of 99. While for zero number of operating fossil fuel powered electricity generating sets, at humidity of 99 (highest obtained level), wind direction relative to the observer of 360, and wind speed of 5 (highest obtained level), the air pollution level was found to be 13.76 around the generator's house, which is within the safe range (0 – 15). It then suggests that replacement of the fossil fuel powered electricity generators with renewable energy sources should be sought rather than the palliative of seeking proper location of the fossil fuel powered generators, considering the space limitation in most of the hostels
Keywords: Fossil fuel, Green Energy, Air Pollution, Multivariate Analysis, Climate Change, Health Safety and Environment.

1. Introduction

The importance of, the ever-growing need for, and attempts to find sustainable means of providing adequate supply of electricity in various aspect of human endeavor have been widely researched and reported. Notable among these are: Akinlo (2009); Poveda and Martínez (2011); Owusu, Asumadu-Sarkodie, Ameyo (2016); Asumadu-Sarkodie and Owusu (2017); Mbachu and Alukwe (*2019);* Ali, Nathaniel, Uzuner, Bekun and Sarkodie (2020); Odekanle, Odejobi, Dahunsi and Akeredolu (2020) and Mbachu, Ovuworie, Okwu and Tartibu (2021). Skelton (2014) independently submitted that adequate electricity supply is important in enhancing learning in schools and quality of education in general. According to Aliyu, Dada and Adam (2015), only 40 percent of Nigeria's populations are connected to her energy grid. Several reasons have been attributed to the failure of the government to provide adequate electricity supply.

Sadly, the general public has given up on the government and has resorted to private electricity generation, which is predominantly via fossil fuel powered generating sets. According to Mbachu, Muogbo, Ezeanaka, Ejimchukwu, Ekwunife (2022), more than half of the students of Nnamdi Azikiwe University that are living off campus have followed suit, not minding the plethora of warning of its effect on the health and safety of humans and their environment. The ease of use, availability of various affordable sizes of generating sets, availability of fossil fuel, and the ignorance or shear negligence of the hazardous effect in the human and environmental health and safety, has resulted to continuous increasing subscription to fossil fuel powered generating sets. Many of the students of Nnamdi Azikiwe University, Awka live off campus. While the university student's hostel operate a central electricity generating set optimally positioned to reduce effect of generator's fumes on the occupants, but this is not so with the students living off campus. These students operate individual generating sets leading to plethora of such pollution source in a building with improper positioning. In 2022, two students of the university living in private hostel (off campus) died of choking from generator's fumes.

The article, Mbachu et al (2022), provided a comparative economic analysis between the uses of Solar Photovoltaic System (SPS) and Fossil fuel powered electricity generators (FFPG) as supplementary electricity source for a typical student apartment. Although, the result of the analysis was in favour of the SPS, considering a 5-year study period, its first cost (procurement cost) seems to be out of reach of the student (in a one-off payment plan). This was also observed by Oladeji, Akorede, Aliyu, Mohammed and Salami (2023) while trying to adopt the use of off-grid power generating and supply system in the rural area. The paper also suggested development of a credit facility plan that presents a win-win situation for the students and the lending company. Albeit, while waiting for the implementation of the policy that encourages shift from FFPG to SPS, there is need to seek palliative measure that will curb the negative effects of the use of FFPG on the users (students). Some efforts have been made in time past, which include: use of longer exhaust pipe with treatment of the fumes before final exit; minimizing the number of hours of use by having optimal job scheduling; routine servicing of the generating sets; use of additives that enhances complete combustion of the fuel among others, see Ezetoha, Fagorite and Urom (2020). In line with the concept of root cause analysis, it is important that the interactions and the contributory effect of these factors on the air pollution level are studied. This will provide basis for proffering solution to the menace and possibly setting operational limits for safety and health of occupants of the area.

2.0 Material and methods

2.1 Research Design

In this study, the air quality around a cluster of generating sets servicing a mega student's hostel around Nnamdi Azikiwe University, Awka Campus was assessed. Kaintain methodology, the use of observed data and logical reasoning, was adopted for this research. In order to appreciate the challenges posed by the cluster on human health and the environment, the pollutants around the cluster were characterized, measured, and analyzed. The interaction between some selected system's parameters and the air quality around the vicinity were obtained through multivariate analysis, such that will aid facility layout decisions. A mega student's hostel with cluster of generating sets, servicing the hostel, was visited; and the ambient air quality was measured at different point from the pollution source (0m, 1m, 2m, 3m, 4m, and 5 meters away from the power generating set – pollution source). Values of other decision variables (Wind speed, wind direction, humidity, gprs position of the observer and others) were obtained alongside with the concentration of each pollutant or the pollution level in the air. The measurement was taken at different scenario (when the generator is in operation, when it is not, and with varying number of generators in use) for about 8 days

2.2 Study Area

For ease of data collection, a mega student's hostel (Divine green hostel) was studied in Nnamdi Azikiwe University, Awka campus. Which is located at Somtochukwu junction, by ifite with coordinate 6°15'17''N 7°6'5''E and its map shown in Figure 1.

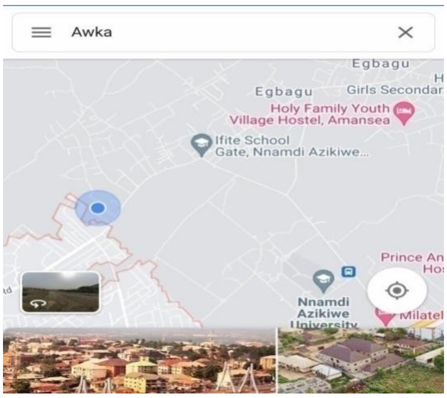

Figure 1: Area map of the study area

2.3 Sample and Sampling Technique

A mega student's hostel with a cluster of generating sets servicing the hostel in Ifite was purposively selected. Out of the three of such hostels in the area, one was randomly selected for the study. The area was selected based on proximity to the campus and density of student population in the area. The selected hostel has 14 electricity generating sets, owned by different occupants, located at a generator house within the compound. This will provide the scenario of different number of generators in use.

2.4 Tools and Method of Data Collection

The instrument employed in identifying the air pollutants, measuring the concentration of such pollutant, and measuring of other system parameters in the study area are described in Figure 2-4. These devices were procured, calibrated and used for the measurement based on the set standards. The intelligent air quality detector when used as a mass profiler provides a fast indication of a particle mass concentration per cubic meter of sampled air. The most commonly tested particle size functions are; PM_1, $PM_{2.5}$, PM_{10}, TVOC.

Figure 2: An Intelligent Air Quality Detector

The device can also detect ambient temperature, humidity and HCHO concentration. It is 224g handheld, portable battery operated, sensor based, LCD device that measures the level of common air pollution. (both indoor and outdoor). The test range is 0.000-1.999 mg/m^3 for formaldehyde (HCHO), 0.000-9.999 mg/m^3 for total volatile organic compound (TVOC). Its battery capacity is 1200mAh, with an input of 5.0V/1A.

Figure 3: wind speed and direction mobile application

This is an application on mobile phones that is used in assessing the direction and the speed of the wind. It was also used to determine the location/ bearing of the user. It also measures wind speed in miles per hour as well as the direction of the flow.

Figure 4.: The Measuring tape

A measuring tape is a flexible ruler used for measuring length, circumference etc. It consists of a ribbon of cloth, plastic, fiberglass, or metal strip with linear-measurement markings. It is a common, light weight, measuring tool. It can measure up to 100m. This was used to measure out the distance from the source - 1,2,3,4,5 meter(s). Measurements were taken twice in each sampling point and the average is taken as the true reading. Fourteen data sets were measured and recorded. Among these data sets are concentration of seven pollutants, which include: formaldehyde (HCHO), Total Volatile Organic Compound (TVOC), suspended particulate matters (PM_1, $PM_{2.5}$, and PM10). Other components of the data sets include: temperature, humidity, air pollution level, wind speed and direction. The handheld intelligent air quality detector was used in measuring the particulate matter (PM_1, $PM_{2.5}$, and PM10) and the total volatile organic compounds (TVOC). Readings were taken by holding and monitoring the sensor closely at the pollution source (fossil fuel powered generating set), then 1m, 2m, 3m, 4m and 5m away from the source.

2.5 Tool and Methods of Data Analysis

Descriptive statistics and multivariate analysis were employed in the data presentation, analysis and modeling of the system behavior. Descriptive statistics was employed for the conversion of the raw data obtained into clearer and useful information. It was used for proper definition and categorization of data points. While multivariate analysis was used as a statistical procedure to provide a regression-based model that explains the interaction between the system parameters and the dependent variables (air pollution level, the air quality status or the concentration of the pollutant). The outcome of the analysis provided the coefficient of each contributing variable in the objective function and t-test was used to determine the level of significance of the variables in determining the value of the dependent variable.

The decision variables include: the number of generating sets that are on (X_1), humidity (X_2), difference between wind direction and position of the observer (X_3), wind speed (X_4), and the distance away from the pollution source (X_5). The dependent variable is the concentration of the pollutants or the general air pollution level as displayed by the intelligent air quality detector. Linear relationship was assumed for the system, and a linear program was developed, whose objective function is given as: Min $Yi= A_1X_1+A_2X_2+ \ldots + A_nX_n$

The values of A_1, A_2 ….and A_n are obtained using the multi-linear regression which defines the effect of each of these decision variables on the dependent variable Y_i. Meanwhile Y_i is the dependent variable that represents either the general air pollution level or the concentration of each pollutant. The optimum value of X_i is obtained by solving the linear equation obtained, such that minimizes the pollution level Y_i. Based on the standard set as safe range of pollution level for human, an optimized range for location of the generating set was obtained.

3.0 Results and Discussions

Comparing the result from the experiment, shown in Table 2, with the range of values in Table 1, it is obvious that the air pollution level of the ambient environment was within the safe range when the generating sets were all switched off, and rises to unsafe ranges when the generating sets are in use (switched on).

Table 1: Air pollution Level Standard

Range	Remark
0-15	Safe
16-29	Normal
30-49	Light
50-69	Medium
70-89	Serious
90 and above	Dangerous

Source: The intelligent air quality detector's manual

The preventive strategy which includes; implementing safe practices, proper use and maintenance of generators, and piping the exhaust emission away from buildings was finally presented. There was further probe on the effect of some factors that were suspected to have influence on the pollution level and concentration of each individual pollutants and temperature in the ambient air. These factors are wind speed, difference in wind direction and observer's direction, humidity of the ambient air, number of generating sets switched on/ operational as at the time of the data collection, distance away from the source of pollution – the generating set.

The result of the regression analysis of the selected 5 causative variables on the air pollution level; HCHO concentration in the air; PM 1.0 concentration in the air; PM 2.5 concentration in the air; PM 10 concentration in the air; TVOC concentration in the air; and the ambient air temperature are presented in tables 3, 4, 5, 6, 7, 8, and 9 respectively. The coefficient of determination varies between 0.68 and 0.97 for various dependent variables measured. Interestingly, the coefficient of determination for the interaction between the decision variables and the ambient temperature was highest (0.97). This shows that 97% of the causes of changes in the ambient temperature were captured by the regression model. Hence global warming in the study area could be managed using the derivatives from the regression model.

Table 2: Input and output data obtained from the experiment

Inputs						outputs						
Trials	**Distance From The Source Of Pollution**	**Wind Speed**	**Humidity**	**Number Of Generator's On**	**Diff Between The Wind And Readers Direction**	**Air Polution Level**	**Hcho**	**Pm 2. 5**	**Pm 1. 0**	**Pm 10**	**Temp**	**Tvoc**
1	0	1	90	0	-2	4	0	10	8	12	30	0
2	1	1	92	0	-2	4	0	10	7	10	29	0
3	2	1	93	0	-2	4	0	10	7	11	29	0
4	3	1	93	0	-2	4	0	9	7	11	28	0
5	4	1	93	0	-2	4	0	9	7	11	29	0
6	5	1	93	0	-2	4	0	9	7	11	29	0
7	0	1	69	14	13	58	0.21	68	19	70	34	1.05
8	1	1	69	14	10	58	0.2	66	19	67	34	1.03
9	2	1	67	14	6	54	0.19	66	17	53	34	1.03
10	3	1	69	14	3	51	0.12	57	15	53	31	0.94
11	4	1	69	14	3	51	0.12	54	15	46	32	0.92
12	5	1	69	14	-2	51	0.12	50	15	31	32	0.83
13	0	3	88	0	16	8	0	22	16	24	28	0
14	1	3	90	0	13	8	0	22	16	24	28	0
15	2	3	92	0	7	8	0	21	16	24	28	0
16	3	3	92	0	7	8	0	21	15	23	28	0

17	4	3	91	0	3	9	0	21	15	24	28	0
18	5	3	90	0	3	9	0	21	15	23	28	0
19	0	1	64	7	-127	41	0.41	70	19	210	35	0.52
20	1	1	64	7	-128	41	0.41	53	19	128	35	0.51
21	2	1	64	7	-128	41	0.41	50	18	50	34	0.51
22	3	1	64	7	-133	41	0.39	31	20	37	34	0.5
23	4	1	64	7	-133	40	0.4	27	20	32	34	0.49
24	5	1	64	7	-133	40	0.33	27	19	27	34	0.49
25	0	1	97	0	1	10	0	26	17	30	27	0
26	1	1	95	0	-2	10	0	25	16	30	27	0
27	2	1	96	0	-6	10	0	26	16	30	27	0
28	3	1	96	0	-9	10	0	27	15	31	26	0
29	4	1	96	0	-9	10	0	27	15	31	26	0
30	5	1	96	0	-14	10	0	26	15	31	27	0
31	0	0	73	7	76	44	0.57	104	79	120	34	0.38
32	1	0	73	7	75	41	0.57	88	66	102	34	0.38
33	2	0	73	7	75	35	0.53	82	61	82	33	0.37
34	3	0	73	7	70	21	0.49	82	61	67	32	0.37
35	4	0	73	7	70	21	0.47	54	41	62	32	0.36
36	5	0	73	7	70	21	0.42	50	38	58	32	0.36
37	0	5	87	0	-159	8	0	15	12	18	32	0
38	1	5	99	0	-162	8	0	19	12	22	26	0
39	2	5	99	0	-166	8	0	20	15	23	26	0
40	3	5	99	0	-169	7	0	19	14	22	27	0
41	4	5	99	0	-169	7	0	19	13	22	27	0
42	5	5	99	0	-174	7	0	20	14	22	27	0
43	0	5	98	0	276	4	0	11	8	12	28	0
44	1	5	98	0	270	4	0	11	8	12	27	0
45	2	5	98	0	262	4	0	11	8	12	27	0
46	3	5	96	0	259	4	0	10	8	12	27	0
47	4	5	96	0	258	4	0	10	7	12	27	0
48	5	5	96	0	258	4	0	10	7	12	27	0
49	0	0	64	14	109	41	0.41	104	79	120	23	0.92
50	1	0	64	14	106	40	0.41	102	77	118	23	0.87
51	2	0	64	14	102	40	0.4	102	77	118	23	0.83
52	3	0	64	14	99	37	0.39	87	66	100	23	0.8
53	4	0	64	14	99	34	0.33	85	64	98	23	0.58
54	5	0	64	14	94	33	0.3	83	63	96	23	0.43
55	0	1	96	0	49	10	0	27	20	30	27	0
56	1	1	99	0	48	10	0	26	19	30	26	0
57	2	1	99	0	48	10	0	26	19	31	27	0
58	3	1	98	0	43	10	0	25	18	31	27	0
59	4	1	97	0	43	10	0	26	19	31	27	0
60	5	1	97	0	43	10	0	26	19	31	27	0
61	0	3	97	0	118	2	0	5	3	5	24	0
62	1	3	95	0	100	2	0	4	3	4	25	0

63	2	3	97	0	94	2	0	5	3	5	25	0
64	3	3	96	0	89	2	0	5	3	5	26	0
65	4	3	96	0	83	2	0	5	4	4	27	0
66	5	3	96	0	83	2	0	5	4	4	26	0
67	0	3	73	7	93	44	0.57	104	79	120	34	0.39
68	1	3	73	7	92	41	0.57	88	66	102	34	0.38
69	2	3	73	7	96	35	0.54	82	61	82	33	0.37
70	3	3	73	7	96	21	0.49	82	61	67	32	0.37
71	4	3	73	7	88	21	0.47	54	41	62	32	0.36
72	5	3	73	7	86	21	0.43	50	38	53	32	0.36
73	0	1	93	0	70	3	0	9	6	10	27	0
74	1	1	94	0	70	3	0	8	6	9	29	0
75	2	1	93	0	68	3	0	8	6	9	27	0
76	3	1	95	0	65	3	0	8	6	9	27	0
77	4	1	93	0	65	2	0	9	6	10	28	0
78	5	1	94	0	64	2	0	8	6	9	28	0
79	0	1	64	14	95	87	0.15	88	26	134	35	0.92
80	1	1	64	14	92	87	0.14	88	19	128	35	0.92
81	2	1	64	14	92	83	0.14	71	19	120	35	0.83
82	3	1	64	14	87	77	0.14	66	17	100	34	0.67
83	4	1	64	14	72	70	0.14	54	15	50	34	0.58
84	5	1	64	14	66	60	0.14	28	15	27	34	0.58

From the linear regression analysis in Table 3, the coefficient of determination r^2 is 0.92, which shows the extent of determination of the dependent variable (air pollution level) from the interaction of the independent variables in the table. The linear regression equation explaining the interaction is obtained using the coefficients of each decision variables represented in the row C_i.

$$y_a = 3.88x_1 + 0.09x_2 + 0,01x_3 + 0.25x_4 - 1.35x_5 \qquad (1)$$

Where, y_a is the corresponding value of the ambient air pollution level; and x_1, x_2, x_3, x_4, and x_5 are the corresponding values of the independent variables: the number of generating sets that are on, humidity, difference between wind direction and position of the observer, wind speed, and the distance away from the pollution source, respectively. From the values of *abs* $(t_{computed}) - t_{critical}$ for the decision variables, which represent the level of significance of the variable in determining the corresponding values the dependent variable (in this case, air pollution level), it could be deduced that: the number of generating sets that are on; humidity; and the distance away from the pollution source were found to be significant contributors to the air pollution level of the ambience. The most significant factor was found to be number of generating set that are currently in use (17.05). From Equation 1 it is seen that moving away from the generating set (pollution source) reduces the air pollution level, and the associated *abs* $(t_{computed}) - t_{critical}$ value suggest that this factor has significant contribution to the air pollution level within the area. Hence this could serve as a palliative measure in militating against pollution from the use of the generating set.

Considering only the significant factors, and making x_5 the dependent variable, the model in equation 1 was modified into Equation 2

$$x_5 = (3.88x_1 + 0.09x_2 - y_a)/1.35 \qquad (2)$$

Based on this model and its derivatives, building codes or policies could be developed for setting optimum distance for positioning of the fossil powered electricity generating sets in homes. Since the safe range of pollution level is 0 to 15, we then adopt the worst-case scenario (15), and use the highest observed humidity level (99), which is directly proportional to the pollution level, in setting the minimum distance for locating the generating set away from the household. Linear regression was used to get the relationship between the number of generating sets in use and the optimum location of the generating sets for safe atmospheric condition. This is shown in Equation 3 and using the X_1 number of generators in use, Corresponding Optimum values of X_5 were determined and presented in Table 4.

$$x_5 = 2.874x_1 - 4.511 \quad (3)$$

Table 3: Linear Regression Analysis of Effect of the Selected 5 Causative Variables on Air Pollution Level

	Number Of Generator's On	Humidity	Between the Wind and Readers Direction	Wind Speed	Distance Away From The Source Of Pollution
C_i	3.881635	0.091586	0.006654	0.248614	-1.34799
S_{ei}	0.203831	0.030112	0.024641	0.884351	0.613526
r^2, S_{ev}	0.916265	9.595599	#N/A	#N/A	#N/A
F, d_f	172.8908	79	#N/A	#N/A	#N/A
SS_{reg}, SS_{resid}	79595.03	7273.965	#N/A	#N/A	#N/A
$f_{computed}$ (0.05,5,6)	172.8908				
Probability of high $f_{computed}$ value occurring by chance			2.7E-43		
$t_{computed}$	19.04337	3.041529	0.27004	0.281125	-2.19712
$t_{critical}$	1.99045	1.99045	1.99045	1.99045	1.99045
abs($t_{computed}$) – $t_{critical}$	17.05292	1.051079	-1.72041	-1.70932	0.206672

Table 4: Corresponding Optimum values of (X_5) at y_a = 15 and humidity = 99

(X_1)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Corresponding Optimum values of (X_5)	-1.64	1.24	4.11	6.99	9.86	12.73	15.61	18.48	21.36	24.23	27.10	29.98	32.85	35.73

As the number of generators increases, the permissible or safe distance for placing the generators away from humans increases. This can serve as guide for establishing building codes in the said area.

For HCHO Concentration in the Air, the regression result in table 4 shows that the interaction of the five selected factors has low coefficient of determination (0.68). Interestingly, the abs ($t_{computed}$) – $t_{critical}$ value shows that *distance away from the generation sets* is not significant in determining the concentration of HCHO in the air, rather the *number of generators in on status*, *difference between the wind and readers direction* and *wind speed* were significant. The linear regression equation explaining the interaction is obtained using the coefficients of each decision variables represented in the row C_i.

For HCHO Concentration in the Air, the regression result in Table 5 shows that the interaction of the five selected factors has low coefficient of determination (0.68). Interestingly, the abs ($t_{computed}$) – $t_{critical}$ value shows that *distance away from the generation sets* is not significant in determining the concentration of HCHO in the air, rather the *number of generators in on status*, *difference between the wind and readers direction* and *wind speed* were significant. The linear regression equation explaining the interaction is obtained using the coefficients of each decision variables represented in the row C_i.

Table 5: Linear Regression Analysis of Effect of the Selected 5 Causative Variables on HCHO Concentration in the Air

	Number of Generator's On	Humidity	Diff Between the Wind and Readers Direction	Wind Speed	Distance Away From The Source Of Pollution
C_i	0.017428	0.000284	0.001614	-0.03369	-0.00302
S_{ei}	0.003084	0.000456	0.000373	0.013382	0.009284
r^2, S_{ev}	0.679267	0.145197	#N/A	#N/A	#N/A
F, d_f	33.46217	79	#N/A	#N/A	#N/A
SS_{reg}, SS_{resid}	3.527277	1.665492	#N/A	#N/A	#N/A
$f_{computed}$ (0.05,5,6)	33.46217				
Probability of high $f_{computed}$ value occurring by chance			8.96E-20		
$t_{computed}$	5.650606	0.623175	4.329553	-2.51733	-0.32498
$t_{critical}$	1.99045	1.99045	1.99045	1.99045	1.99045
abs($t_{computed}$) – $t_{critical}$	3.660156	-1.367275	2.339103	0.526877	-1.66547

For HCHO Concentration in the Air, the regression result in Table 4 shows that the interaction of the five selected factors has low coefficient of determination (0.68). Interestingly, the abs ($t_{computed}$) – $t_{critical}$ value shows that *distance away from the generation sets* is not significant in determining the concentration of HCHO in the air, rather the *number of generators in on status, difference between the wind and readers direction* and *wind speed* were significant. The linear regression equation explaining the interaction is obtained using the coefficients of each decision variables represented in the row C_i.

$$y_b = 0.0174x_1 + 0.0003x_2 + 0{,}0016x_3 - 0.0337x_4 - 0.0030x_5 \qquad (4)$$

y_b is the corresponding value of the HCHO Concentration in the Air; and x_1, x_2, x_3, x_4, and x_5 are as defined earlier.

From Equation 4 it is seen that moving away from the generating set (pollution source) and the increase in the wind speed reduces the concentration of HCHO in the ambient air. The result suggests that positioning of the generators does not have significant contribution on the concentration of the pollutant in the ambient air and the pollutant can be easily dispersed by wind.

The regression result in Table 6 shows that the interaction of the five selected factors also has low coefficient of determination (0.71) for the concentration of PM 1.0 in the Air. Also, the abs ($t_{computed}$) – $t_{critical}$ value shows that *distance away from the generation sets* is not significant in determining the concentration of PM 1.0 in the Air, rather the *number of generators in on status, the humidity, difference between the wind and readers direction*, and *wind speed* were significant determinant of the concentration of the pollutant. The linear regression equation explaining the interaction is shown in Equation 5:

$$y_c = 1.955x_1 + 0.193x_2 + 0{,}128x_3 - 3.771x_4 - 1.386x_5 \qquad (5)$$

y_c is the corresponding value of the concentration of PM 1.0 in the Air; and x_1, x_2, x_3, x_4, and x_5 are as defined earlier. Also, from Equation 5 it is seen that moving away from the generating set (pollution source) and increase in the wind speed reduces the concentration of PM 1.0 in the air.

Table 6: Linear Regression Analysis of Effect of the Selected 5 Causative Variables on PM 1.0 Concentration in the Air

	Number of Generator's On	Humidity	Diff Between the Wind and Readers Direction	Wind Speed	Distance Away From The Source Of Pollution
C_i	1.955372	0.192672	0.127731	-3.77077	-1.38588
S_{ei}	0.379001	0.055989	0.045817	1.644349	1.14078
r^2, S_{ev}	0.70753	17.8419	#N/A	#N/A	#N/A
F, d_f	38.22261	79	#N/A	#N/A	#N/A
SS_{reg}, SS_{resid}	60837.66	25148.34	#N/A	#N/A	#N/A
$f_{computed}$ (0.05,5,6)	38.22261				
Probability of high $f_{computed}$ value occurring by chance			2.06E-21		
$t_{computed}$	5.159285	3.441227	2.787847	-2.29317	-1.21485
$t_{critical}$	1.99045	1.99045	1.99045	1.99045	1.99045
abs($t_{computed}$) – $t_{critical}$	3.168834	1.450777	0.797397	0.302721	-0.7756

Table 7: Linear Regression Analysis of Effect of the Selected 5 Causative Variables on PM 2.5 Concentration in the Air

	Number of Generator's On	Humidity	Diff Between the Wind and Readers Direction	Wind Speed	Distance Away From The Source Of Pollution
C_i	4.685666	0.298922	0.094097	-3.0462	-3.36837
S_{ei}	0.361725	0.053437	0.043729	1.569398	1.088782
r^2, S_{ev}	0.888873	17.02865	#N/A	#N/A	#N/A
F, d_f	126.3798	79	#N/A	#N/A	#N/A
SS_{reg}, SS_{resid}	183235	22908.03	#N/A	#N/A	#N/A
$f_{computed}$ (0.05,5,6)	126.3798				
Probability of high $f_{computed}$ value occurring by chance			2.21E-38		
$t_{computed}$	12.95365	5.593903	2.151832	-1.941	-3.0937
$t_{critical}$	1.99045	1.99045	1.99045	1.99045	1.99045
abs($t_{computed}$) – $t_{critical}$	10.9632	3.603453	0.161382	-0.04945	1.103251

The regression result in Table 7 shows that the interaction of the five selected factors and the concentration of PM 2.5 has higher coefficient of determination (0.89). Also, all the considered factors except the wind speed were found to have significant contribution to the concentration of PM 2.5 in the ambient air. Interestingly, the abs($t_{computed}$) – $t_{critical}$ value shows that *distance away from the generation sets* and *number of generators in on status are* significant in determining the concentration of PM 2.5 in the air. Hence the linear regression equation in Equation 6 can be used to develop palliative policy against the pollutant. The linear regression equation explaining the interaction is obtained using the coefficients of each decision variables represented in the row C_i.

$$y_d = 4.686x_1 + 0.299x_2 + 0{,}094x_3 - 3.046x_4 - 3.368x_5 \quad (6)$$

y_d is the corresponding value of the concentration of PM 2.5 in the ambient air; and x_1, x_2, x_3, x_4, and x_5 are as defined earlier.

From the result in Table 8, the interaction of the five selected factors has relatively high coefficient of determination (0.83) for the dependent variable (concentration of PM 10 in the ambient air). Here, all the considered factors were found to have significant contribution to the concentration of PM 10 in the ambient air. To a very large extent, the increase in the concentration of the pollutant in the ambient air can be traced to the use of the fossil powered electricity generating sets, and the linear regression equation in Equation 7 can be used to develop palliative policy against this pollutant.

$$y_e = 5.177x_1 + 0.390x_2 + 0.244x_3 - 6.361x_4 - 6.247x_5 \quad (7)$$

y_e is the corresponding value of the concentration of PM 10 in the ambient air; and x_1, x_2, x_3, x_4, and x_5 are as defined earlier.

Table 8: Linear Regression Analysis of Effect of the Selected 5 Causative Variables on PM 10 Concentration in the Air

	Number of Generator's On	Humidity	Between the Wind and Readers Direction	Wind Speed	Away From The Source Of Pollution
C_i	5.176633	0.390101	0.244329	-6.36098	-6.24662
S_{ei}	0.553809	0.081813	0.066949	2.402782	1.666949
r^2, S_{ev}	0.833621	26.07123	#N/A	#N/A	#N/A
F, d_f	79.16388	79	#N/A	#N/A	#N/A
SS_{reg}, SS_{resid}	269042	53697.01	#N/A	#N/A	#N/A
$f_{computed}$ (0.05,5,6)	79.16388				
Probability of high $f_{computed}$ value occurring by chance			2.41E-31		
$t_{computed}$	9.347321	4.768184	3.649457	-2.64734	-3.74733
$t_{critical}$	1.99045	1.99045	1.99045	1.99045	1.99045
abs($t_{computed}$) – $t_{critical}$	7.356871	2.777734	1.659006	0.656888	1.756884

For the TVOC Concentration in the Air, the regression result in Table 9 shows that dependent variable (TVOC Concentration in the Air) has relatively very high coefficient of determination (0.97) from the interaction of the five selected factors. Also, only the *distance away from the generation sets and the number of generators in on status* has positive abs ($t_{computed}$) – $t_{critical}$ value. This implies that only these factors have significant effect on the dependent variable. In other words, the change in the concentration of *total volatile organic acids* is chiefly caused by fumes resulting from the use of fossil fuel powered electricity generating sets generating sets.

The linear regression equation explaining the interaction is:

$$y_f = 0.0607x_1 + 0.0005x_2 - 0{,}0003x_3 + 0.0061x_4 - 0.0168x_5 \quad (8)$$

y_f is the corresponding value of the *total volatile organic acids* Concentration in the Air; and x_1, x_2, x_3, x_4, and x_5 are as defined earlier. From Equation 8, moving away from the generation sets and reducing the number of generating set in use reduces the concentration of TVOC in the ambient air. Therefore, getting minimum number of generating set in use per area and optimum positioning of the generating set will provide basic information for developing building codes and policies. The interaction of the five factors showed highest coefficient of determination (0.98) with ambient air temperature. Nevertheless, only humidity and number of generating sets in on status had significant effect on the value of the ambient air temperature. From Table 10 and Table 11, the level of insignificance of the *distance away from the source of pollution* suggests that the increase in the ambient temperature cannot be appropriately managed by the location of the generating set.

Table 9: Linear Regression Analysis of Effect of the Selected 5 Causative Variables on TVOC Concentration in the Air

	Number of Generator's On	Humidity	Between the Wind and Readers Direction	Wind Speed	Distance Away From The Source Of Pollution
C_i	0.060736	0.000469	-0.00026	0.006107	-0.01675
S_{ei}	0.001754	0.000259	0.000212	0.007609	0.005279
r^2, S_{ev}	0.965882	0.082556	#N/A	#N/A	#N/A
F, d_f	447.2929	79	#N/A	#N/A	#N/A
SS_{reg}, SS_{resid}	15.2427	0.538427	#N/A	#N/A	#N/A
$f_{computed}$ (0.05,5,6)	447.2929				
Probability of high $f_{computed}$ value occurring by chance			8.38E-59		
$t_{computed}$	34.63334	1.811849	-1.21942	0.80262	-3.17265
$t_{critical}$	1.99045	1.99045	1.99045	1.99045	1.99045
abs($t_{computed}$) – $t_{critical}$	32.64289	-0.1786	-0.77103	-1.18783	1.1822

Table 10: Linear Regression Analysis of Effect of the Selected 5 Causative Variables on the Ambient Air Temperature

	Number of Generator's On	Humidity	Between the Wind and Readers Direction	Wind Speed	Away From The Source Of Pollution
C_i	0.944508	0.29186	0.010972	-0.09984	-0.05501
S_{ei}	0.092251	0.013628	0.011152	0.400244	0.277672
r^2, S_{ev}	0.979491	4.342817	#N/A	#N/A	#N/A
F, d_f	754.6112	79	#N/A	#N/A	#N/A
SS_{reg}, SS_{resid}	71160.06	1489.945	#N/A	#N/A	#N/A
$f_{computed}$ (0.05,5,6)	754.6112				
Probability of high $f_{computed}$ value occurring by chance			1.45E-67		
$t_{computed}$	10.23848	21.41607	0.983855	-0.24944	-0.19811
$t_{critical}$	1.99045	1.99045	1.99045	1.99045	1.99045
abs($t_{computed}$) – $t_{critical}$	8.248031	19.42562	-1.0066	-1.74101	-1.79234

Rather, minimization of the number of generating set in use, which is the only controllable parameter with significant impact on the dependent variable. This becomes the only feasible solution to the increase in ambient air temperature. The linear regression equation explaining the interaction is:

$$y_g = 0.9445x_1 + 0.2919x_2 + 0,0110x_3 - 0.0998x_4 - 0.0550x_5 \quad (9)$$

where, y_g is the corresponding value of the ambient air temperature; and x_1, x_2, x_3, x_4, and x_5 are as earlier defined.

The low r^2 in PM1.0, PM 2.5 and PM 10 suggest that either the factors are not fully captured in the model or the model does not effectively explain the interactions between the captured factors. Further transformation of the model to polynomial of 2nd degree was sought:

Table 11: Summary of level of significance of these factors on pollution level and concentration of pollutants in the air

	r^2	$\text{abs}(t_{\text{computed}}) - t_{\text{critical}}$	Number of Generator's On	Humidity	Diff Between the Wind and Readers Direction	Wind Speed	Distance Away From The Source Of Pollution
Air pollution level	0.93		17.05292	1.051079	-1.72041	-1.70932	0.206672
HCHO Concentration in the Air	0.68		3.660156	-1.367275	2.339103	0.526877	-1.66547
PM 1.0 Concentration in the Air	0.71		3.168834	1.450777	0.797397	0.302721	-0.7756
PM 2.5 Concentration in the Air	0.89		10.9632	3.603453	0.161382	-0.04945	1.103251
PM 10 Concentration in the Air	0.83		7.356871	2.777734	1.659006	0.656888	1.756884
TVOC Concentration in the Air	0.97		32.64289	-0.1786	-0.77103	-1.18783	1.1822
Ambient Air Temperature	0.98		8.248031	19.42562	-1.0066	-1.74101	-1.79234

The non-linear Regression model is stated below

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \beta_{n+1} x_1^2 + \beta_{n+2} x_1 x_2 + \cdots + \beta_{n+m} x_n{}^2 \quad (10)$$

Where: y is the dependent variable (the target variable). x_1, $x_2,\cdots\cdots,x_n$ are the original features. $x_1{}^2$, $x_1 x_2$ $\cdots$, $x_n{}^2$ are the polynomial features generated by Polynomial Features. β_0, β_1, $\beta_2,\cdots$, β_{n+m} are the coefficients of the linear regression model. So, the model includes linear terms for each original feature (x_1, $x_2,\cdots\cdots,x_n$) as well as polynomial terms up to degree 2 for each feature. These polynomial terms capture the interaction between features and higher-order relationships between them.

The following R squared was obtained:
'air polution level': 0.922536128455731,
'Hcho': 0.9778123127893424,
'pm 2. 5': 0.9707954117827474,
'pm 1. 0': 0.9346432939374786,
'pm 10': 0.9126966232666814,
'temp': 0.884606379772807,
'Tvoc': 0.9913069733967184

The model intercepts when different inputs are used were gotten as:
'air polution level': 22.7738,
'Hcho': 0.149,
'pm 2. 5': 38.6786,
'pm 1. 0': 23.4524,
'pm 10': 45.8214,
'temp': 29.1905,
'Tvoc': 0.2643

Coefficients of the model when different outputs are used are :
{'air polution level': array
([-2.199050e+01, -2.428305e+02, 2.679260e+01, 1.699602e+02, -1.425068e+02, 1.474600e+00, 1.513000e-01, 1.926580e+01, -2.155000e-01, -3.633000e+00, 9.708480e+01, 1.735612e+02, 4.001850e+01, 7.947400e+00, -5.364420e+01, -1.817584e+02, 1.454493e+02, -1.025300e+00, 1.510100e+01, -4.111420e+01]),

'Hcho': array
([-0.0991, 1.384 , -0.4911, 1.036 , 1.0365, -0.0147, -0.0038, 0.1041, 0.0074, -0.0138, -0.1409, -1.3118, -0.2231, 0.0263, 0.6511, 0.0421, -1.0084, -0.76, -0.1301, 0.0741]),

'pm 2. 5': array
([-72.238, 216.4279, -540.0942, -191.0253, 211.4507, -1.2414, -2.2919, 68.367, 8.6484, -5.1639, 32.1354, -249.3297, -33.5899, 24.2947, 516.1961, 215.1825, -212.4652, -14.8487, -20.9612, -10.6146]),

'pm 1. 0': array
([-28.1275, 311.9982, -672.5232, -305.3412, 281.1465, -0.8067, -0.8371, 27.0119, 4.5404, -7.5038, 29.7246, -345.9523, -49.5047, 19.2813, 647.8795, 297.6518, -270.7314, 1.362 , -30.8272, -7.0616]),

'pm 10': array
([-208.3425, 147.8667, -782.6989, -487.5161, 115.4563, 8.2463, -5.2027, 185.0442, 33.5965, 6.9265, -73.1898, -95.178, -25.9804, 23.3058, 691.4067, 431.9074, -148.9964, 6.5229, 13.6028, 24.4905]),

'temp': array
([-4.17920e+00, -9.41706e+01, 7.47414e+01, 6.52865e+01, -6.25081e+01, 5.38400e-01, 2.18500e-01, 3.50970e+00, 1.17000e-02, -7.57200e-01, 3.51564e+01, 6.86733e+01, 1.53905e+01, 8.18300e-01, -8.17574e+01, -6.91841e+01, 6.40126e+01, -4.49590e+00, 5.85790e+00, -1.36599e+01]),

'Tvoc': array
([0.271 , 0.4287, 0.1097, -0.3048, 0.0867, -0.0262, 0.0099]).

4.0. Conclusion

Interestingly, the level of pollution in the air reduces as the distance between the location of the generating set(s) and the sphere of interest (x_5) increases, and its effect on the air pollution level is significant. This supports the submissions of Adenubi and Mmom (2019) and Ogbuewu and Nnajib (2023), which noted that electricity generator fume and its related pollutants are silent killers and then recommended that Electricity Generator House (EGH) should be far from the living house with enough ventilation. Albeit, the reduction in the number of generating sets in use (x_1) has more significant effect in minimizing the air pollution level. More so, the fact, as presented by the result in table 10 suggests that number of generating sets in use significantly affects the concentration of all the considered classes of pollutant in the air, the ambient temperature and the overall air pollution level, while the effect of increasing x_5 value does not have significant effect on the concentration of some of the considered pollutants in the air (HCHO, PM 1.0), as well as the ambient air temperature. The results of Ahmed et al.(2020) show that when the generators are used, high concentrations of PM1, PM2.5 and PM10 are released; and this exposes the students and staff of their university to health hazards.

Neglecting the insignificant factors (x3 and x4) on the overall air pollution level, Equation 3 gave the relationship between the number of generating sets in use and its location for an air pollution level of 15 and humidity of 99. The result from the computation suggested that the value of x_5 increases to as far as 35.73 meters for hostels operating 14 generating sets, and such distance is usually not obtainable in such hostels. Equation 1 was then simulated for zero number of operating fossil fuel powered electricity generating sets (Abstinence), humidity of 99 (highest obtained level), wind direction relative to the observer of 360, wind speed of 5 (highest obtained level), and zero distance away from the pollution source, the air pollution level was found to be 13.76 which is within the safe range (0 – 15). It could then be concluded that the removal of all fossil fuel powered electricity generating sets (abstinence) rather than palliative measure of distancing the location of the generating sets from sphere of concern is surer means of minimizing air pollution level and having safe environment in the student’s hostels. If then, the *cannot-do-without* situation continues, the safest location of the generator’s house will be at least 35.73 meters from the house, for the 14 generators operating in the hostel. This distance reduces as the number of generators in use reduces.

References

Adenubi B.C. and Mmom, P.C. (2019) Community Exposure to Indoor Air Pollution arising from the Use of Gasoline Generator in Rukpokwu, Port Harcourt, Rivers State, Nigeria. *International Journal of Health, Safety and Environments (IJHSE)* 5 (03) Pp. 383-398 www.academiascholarlyjournal.org/ijhse/index_ijhse.htm

Ahmed, W. K., Abed, T. A., Salam, A. Q., Reza, K. S., Mahdiy, M. T., and Chaichan, M. T. (2020) Environmental Impact of Using Generators in the University of Technology in Baghdad, Iraq. *Journal of Thermal Engineering*, 6 (6) Special Issue 12, pp. 272-281

Ajao, K. R., Ajimotokan, H. A., Popoola, O. T., Akande, H. F., 2009. Electric energy supply in Nigeria, Decentralized Energy approach. *Cogeneration & Distributed Generation Journal* [online], 24 (4), Available at: http://dx.xoi.org/10.1080/15453660909595149

Akinbulire, T. O., Oluseyi, P. O., Awosope, C.O.A., Okoro, O. I., 2008. Data-based analysis of power system crisis in Nigeria. ESPTAEE 2008 [online]; available at: http://www.unilag.edu.ng/opendoc.php?sno=12448&doctype=doc&docname=$

Akinlo, A.E., 2009. Electricity consumption and economic growth in Nigeria: Evidence from co-integration and co-feature analysis. *Journal of Policy Modelling* [online], 31 (5), 681-692; available: http://dx.xoi.org/10.1016/j.jpolmod.2009.03.004

Ali, H.S., Nathaniel, S.P., Uzuner, G., Bekun, F.V., Sarkodie, S.A., 2020. Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria: Fresh insights from Maki Cointegration and causality tests. *Heliyon* , 6 (2), e03400.

Aliyu, A.S., Dada, J.O., Adam, I.K., 2015. Current status and future prospects of renewable energy in Nigeria. *Renewable and Sustainable Energy Reviews*, 48, 336-346.

Asumadu-Sarkodie, S., Owusu, P.A., 2017. Recent evidence of the relationship between carbon dioxide emissions, energy use, GDP, and population in Ghana: A linear regression approach. *Energy Sources Part B Econ. Plan. Policy*, 12 (6), 495–503

Cepin, M., 2011. Distribution and Transmission System Reliability Measures. Assessment of Power System Reliability [online], 215 – 226, London: Springer-Verlag. Available at http://dx.xoi.org/10.1007/978-0-85729-688-7_14

Chinwuko, E.C., Mgbemena, C.O., Aguh, P.S., Ebhota, W.S., 2011. Electricity Generation and Distribution in Nigeria: Technical issues and solutions. *International Journal of Engineering Science and Technology* [online], 3 (11), 7934 – 7941; available http://www.ijest.info/docs/IJEST11-03-11-131.pdf

Diniz, A.S.A.C., França, E. D., Câmara, C. F., Morais, P. M. R., Vilhena, L., 2006. The Important Contribution of Photovoltaics in a Rural School Electrification Program, Transactions of the IEEE. 2, 2528-2531.

Ezetoha, N. O., Fagorite, V. I. and Urom, O. O. (2020) Generators' Harmful Exhaust Emissions in Buildings: Effects on Humans and Preventive Strategy. *International Journal of Engineering Inventions* 9(4) pp: 09-14. www.ijeijournal.com

Gujba, H., Mulugetta, Y., Azapagic, A., 2011. Power generation scenarios for Nigeria: An environmental and cost assessment. *Energy Policy*, 39 (2), 968 – 980.

Ibitoye, F.I., Adenikinju, A., 2007. Future demand for electricity in Nigeria. *Applied Energy* [online], 84(5), 492-504; available at: http://www.sciencedirect.com

Makoto K., Toshihiko N., 2008. Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries, *Energy Policy* 36, 2016–2029

Mbachu, V. M., Muogbo, G. A., Ezeanaka, S.O., Ejimchukwu, E. O., Ekwunife, T. D., 2022. An Economic Based Analysis of Fossil Fuel Powered Generator and Solar Photovoltaic System as Complementary Electricity Source for a University Student's Room. *Journal of Solar Energy Research* 7(4), 1159 – 1173. doi:10.22059/jser.2021.332724.1225

Mbachu, V. M., Alukwe, U., 2019. Biogas production using liquid extract from plantain pseudo stem. *International journal of engineering & industry*. ISSN:2191-3315, 2, (2), 9-14.

Mbachu, V.M., Ovuworie, G.C., Okwu M.O., Tartibu, L.K., 2021. Modelling sustainability of a demand-based biomass to biogas conversion system: a bio-mimicry feedstock inventory-based approach. *Biomass Conversion and Biorefinery*, https://doi.org/10.1007/s13399-021-01581-z,

Odekanle, E.L., Odejobi, O.J., Dahunsi, S.O., Akeredolu, F.A., 2020. Potential for cleaner energy recovery and electricity generation from abattoir wastes in Nigeria. *Energy Rep*. 6, 1262–1267.

Ogbuewu, I, and Nnajib, J.C., 2023 Electricity Generator Emission and Its Impacts on Air Quality to the Environment. *Asian Journal of Green Chemistry* 7 pp 132-139

Oladeji A.S., Akorede M.F., Aliyu S., Mohammed A.A., Salami A.W., 2023. Overview of Off-Grid Rural Electrification Programme in Nigeria. *Journal of Sustainable Energy* 14(2), 104 - 119.

Oseni, M.O., 2012. Households' access to electricity and energy consumption pattern in Nigeria. *Renewable and Sustainable Energy Reviews* 16 (6), 3967 – 3974.

Owusu, P.A., Asumadu-Sarkodie, S., Ameyo, P., 2016. A review of Ghana's water resource management and the future prospect. *Cogent Eng*. 3, 1164275

Poveda, A.C., Martínez, C.I.P., 2011. Trends in economic growth, poverty and energy in Colombia: Long-run and short-run effects. *Energy Syst.* 2 (3), 281–298

Sambo, A., 2008. Matching Electricity Supply with Demand in Nigeria. International Association for Energy Economics 4, 32-36.

Sambo, A.S., 2010. Renewable energy development in Nigeria. Presented at the world future council \strategy workshop on Renewable Energy, Accra, Ghana, 2010.

Skelton, A., 2014. Leveraging funds for school infrastructure: The South African 'mud schools' case study. *International Journal of Educational Development* 39, 59-63.

Van den Berg, S., 2008. How effective are poor schools? Poverty and educational outcomes. Studies in Educational Evaluation 34, 145–154