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ANALYSIS OF ENVIRONMENTAL HAZARD PARAMETERS OF THE WORKPLACES IN STEEL PLANTS IN NIGERIA

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Abstract. The steel plant's workplace environmental hazard parameters in Ilorin, Nigeria was evaluated using response surface methodology (RSM). Three environmental parameters (illumination, temperature and noise level) were measured. The data obtained were compared with the Occupational Safety and Health (OSHA) standard for the workplace environment. Based on the preliminary analysis of the workplace environment, five variables (No. of lightings, no. of windows, no. of machines, no. of workers and age of machines) were considered as input parameters. RSM was used to perform the modelling and optimization to identify functional relationships between the input and output parameters. Three (3) model equations one for each of the output parameters were developed and checked for adequacy and validity. All developed model equations were found to present functional relationships between input and output parameters. Hence, all developed model equations can be used as reliable tools for estimating, predicting, and conducting analysis for workplace environmental hazard. Best optimized results were selected based on desirability (0–1). Illumination, temperature and noise level got desirability rate of 0.921, 1.000 and 0.983 respectively. The outcome of this study suggested that the environmental parameters studied within the workplace do not conform with the OSHA standard and as a result may constitute long-term health risks to the workers.

Keywords: illumination, noise, steel, temperature, workplace safety

Introduction

Despite advances in technology, human factors engineering (ergonomics), preventive medicine, efforts of International Labour Organization (ILO) to prevent industrial accidents, over a million occupational injuries and work-related hazard still occur annually worldwide [1]. In Nigeria, the workplace situation is not different from the world outlook. Many employees suffer from various forms of job-related accidents as the impact of economic volatility takes its toll on the country's workforce. Analysts say the work environment is becoming increasingly dangerous for millions of workers in different sectors of the economy. This is traceable to the regular exposure to unsafe work conditions with resultant increase in cases of injuries and deaths [2]. Other factors responsible for this menace are inadequate supervision, poor awareness of work-related risks, slow response to workplace emergencies, and lack of occupational health services.

Over the years, the wellbeing of workers has been a compulsory subject among stakeholders and human relation experts. This is because of surge in number of reported cases of industrial accidents which is unprecedented. Regular exposure to worsening environment conditions could affect productivity and social wellbeing of workers. However, almost all workplaces present environmental hazards, including iron and steel production industries. They are more common in the informal sector, where little emphasis is placed on safe work practices.

Additionally, modern life without steel production is unimaginable because of its importance in industrialization today. Steel is an alloy predominantly of iron and carbon, usually containing the measurable amount of manganese and readily formable [3]. Generally, steel rods in bars are used for columns and structural reinforcement. It also finds more comprehensive applications in the production of nails, screws, industrial tools, domestic utensils and other household utilities. Geographically, steel industries are primarily situated in remote locations where there are deposit of iron ore, limestone and available water for beneficiation. However, medium-size rolling mills and small-scale steel production facilities are also found in the urban areas, especially where there is a relatively stable power supply.

A number of factors have been identified to affect steel production in the industry, some of which are inadequate financing, difficulty in obtaining credit facilities, small-scale economy of industries, and lack of requisite skills necessary for hi-tech equipment. However, findings from the literature revealed that some of these drawbacks are due to certain inadequacies in the industrial environment. These include poor lighting, insufficient ventilation, excess heat, poor housekeeping, and deficient knowledge on protective measures, among others [4][5]. These situations combined thus limit productivity and increase exposure of workers to hazards [1].

Although government legislation and labour laws have been established to address workplace environmental unsafe conditions, there are still several reported cases of uncertainties. Some of these include physical injuries such as cuts, muscle sprains, muscle pain, dislocations, fractures, and burns which often result during work operations. Others are hearing impairment from loud noises, eye injuries due to UV-radiations and respiratory dysfunctions often caused by noxious metal fumes inhaled [6]. Indeed, these environmental hazards nagatively impact an organisation's economic performance.. It causes person-hour loss, machine downtime, hospitalization, disability and fatality [4].

Undoubtedly, report of accidents is becoming a cause for concern in the manufacturing sector. It is thus necessary to examine workplace hazards and develop reliable tools for estimating and predicting adequacy of safety compliance, particularly in a steel industry with its associated risk effects. The workplace should be a safe place. Therefore, this research aims to evaluate workplace environmental hazard parameters of a steel industry in Ilorin, Nigeria, and develop model equations that can be used to predict and analyze workplace hazards. Also, results obtained are to be compared with Occupational Safety and Health Administration (OSHA) [7] and National Institute for Occupation Safety and Health [8] standards.

Experimental Approach

Data collection

Quantitative data from 61 workers from three different sections of a steel production industry is collected using questionnaires. The sections involved in the research are the wire-drawing, binding-wire, and nail-production, respectively. The data collected details the worker's health, wellbeing and the environmental conditions of the workplace. Environmental parameters such as temperature, illumination and noise level are also measured and recorded. The data is then analyzed. Response Surface Methodology (RSM) is used to perform modelling and optimization. Results were compared with Occupational Safety standards

Workplace illumination

A hand-held digital light intensity meter model no HS1010A was used to measure the light intensity. It has a capacity of 0.1–200.000 lux with an accuracy of ± 3 %. The light meter has four control ranges position to measure light intensity, but it was set at lux one for this research. The light meter was taken to each work station for a stay time of 10 seconds. It was noted with a stop-watch after which a corresponding light-intensity reading was taken on the digital display screen. Several readings were taken, and the average value was recorded. The same procedure was repeated for other work stations.

Workplace temperature

The workplace temperature was measured using a digital crystal thermometer. The thermometer was placed in each work station at a location away from direct contact to heat. The ambient temperature of the location was taken. At intervals of two hours, the temperature readings of workplace were taken and recorded. Several readings were taken, and the average value was recorded. The same procedure was repeated for other workplaces.

Workplace noise level

The noise level measurement of the workplace was determined using an impulse integrating sound level meter with model no GB2274431. It can measure noise levels over a range of 30–130 dBA with an accuracy of ± 5 %. The noise meter was placed in a work location free from obstruction. The windscreen on the meter microphone was firmly in place to prevent unwanted interference that could distort the measurement. Reading was taken after a stay time of 10 seconds on the digital display. Several readings were taken, and the average was calculated. The same procedure was repeated for other workplaces.

Results and Discussion

The results of the binding-wire, wire-drawing and nail production sections are as shown in Tables 1–10 and Fig. 1–6. The parameters obtained were compared with OSHA [7]. From Table 1, the mean temperature in the binding-wire section is 27.9 °C which is relatively above the temperature recommended by OSHA standard. Similarly, the average temperature at the drawing and nail sections is 26.4 % and 28.6 % more than the recommended standard's upper limit, respectively. The higher temperature values are due to the effects of radiation from the working machines in the factory. Invariably, it means the work environment is unsafe because at body temperature substantially higher than the optimal levels (36.5–37.5 °C), both physical and mental performances deteriorate. As further revealed in Fig. 1, the nail-production section has the highest temperature of all. Therefore, prolonged exposure to heat stress will lead to loss of body fluid (dehydration) and psychomotor malfunction, which further reduces performance.

Table 1

Parameters in binding-wire section

Parameter	Range	OSHA standard	Mean
Temperature (℃)	26.00–30.50	20.0–24.00	27.90
Illumination (lux)	268.00–336.00	200.00–500.00	309.27
Noise (dBA)	80.60–90.10	85.00	84.89

Table 2

Parameters in wire-drawing section

Parameter	Range	OSHA standard	Mean
Temperature (℃)	26.00–34.00	20.00–24.00	30.32
Illumination (lux)	112.00–138.00	200.00–500.00	126.47
Noise (dBA)	70.50–87.30	85.00	80.75

Table 3

Parameters nail production section

Parameter	Range	OSHA standard	Mean
Temperature (℃)	26.50–34.50	20.00–24.00	30.87
Illumination (lux)	107.00–129.00	200.00–500.00	115.93
Noise (dBA)	95.20–103.20	85.00	99.29

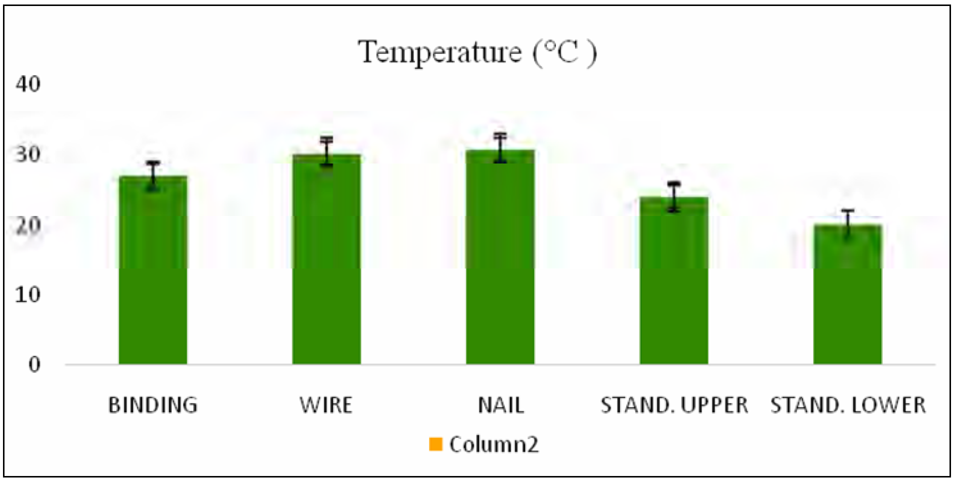


Fig. 1. Temperature at sections compared with standard

The Illumination intensity in the binding-wire section as shown in Table 1 ranged from 268 to 366 lux with a mean value of 309.37 lux. It is acceptable because it is within the limit of OSHA recommended standard for luminous intensity for workplace. However, the illumination values were 126.45 lux and 115.93 lux for the wire-drawing and nail-production sections. These values were far below the recommended standard. It means the work environments in both cases were poorly illuminated as revealed in Fig. 2. According to energy efficiency guide for Industry [9], the illumination between 200 to 500 lux satisfies workers. In effect, workers in these sections are endangered as their vision will be impaired due to insufficient illumination.

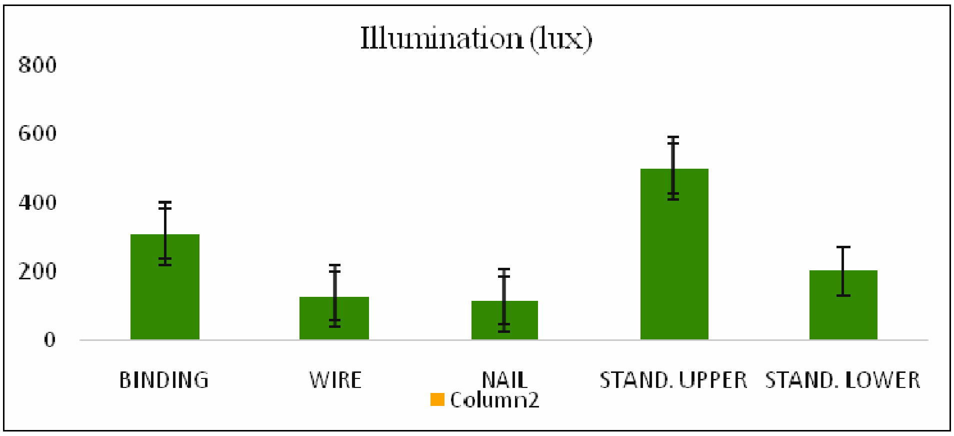


Fig. 2. Illumination at sections compared with standard
(*** STAND. UPPER:** STANDARD UPPER LIMIT; **STAND. LOWER**: STANDARD LOWER LIMIT)

Fig. 3 revealed the noise level in various sections. It is clear from the chart that the nail-production section is the noisiest of all. Unarguably, it is the heart of the production process with many moving machines all working simultaneously. The mean value of the noise level at the binding-wire and wire-drawing sections, as shown in Table 1 and 2 are 84.89 dBA and 80.75 dBA. These values were almost at par with the acceptable standard. However, the mean value at the nail-production section was 16.8 % more than the recommended value. This implies that workers in the nail-production section will experience hearing impairments and psychosocial disorders resulting from protracted exposure to noise. Exposures at or above 85 dBA level are considered hazardous [7].

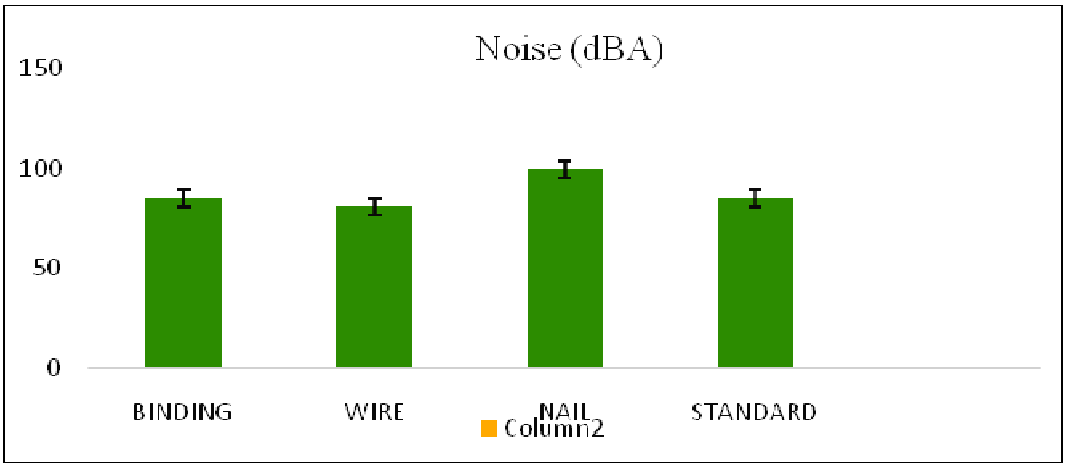


Fig. 3. Noise level at sections with standard

Tables 4, 5 and 6 show the analysis of variance (ANOVA) for the parameters under study. Table 4 revealed that the input variables; no. of lightings (A), no. of workers (C) and no. of machines (D) as well as their interactions are significant on temperature ($p \leq 0.05$). Similarly, Table 5.0 revealed that the input variable no. of lightening (A), no. of windows (B) as well as their interactions are significant at $p \leq 0.05$. Also, Table 6 showed that the input variable no. of workers (C), no. of machines (D) and the age of machines (E) as well as their interactions are significant at the noise level. The interpretation is that all the inputs variables have significant effects on temperature, illumination and noise level at $p \leq 0.05$.

Table 4

Statistical analysis (ANOVA) for illumination

Source	Sum of squares	DF	Mean square	F-value	Significant
Model	358.92	5	71.78	17.75	0.0008*
A	294.00	1	229.00	72.69	0.0001*
B	0.00	1	0.00	0.00	1.0000
A^2	39.74	1	39.74	9.83	0.0165*
B^2	4.02	1	4.02	0.99	0.3518
AB	25.00	1	25.00	6.18	0.0418*
Residual	28.32	7	4.04	–	–
Total	287.23	12	–	–	–
* Significant at $p \leq 0.05$					

Table 5

Statistical analysis (ANOVA) for temperature

Source	Sum of squares	DF	Mean square	F-value	Significant
Model	146.95	9	16.33	79.47	<0.0001*
A	48.35	1	48.35	235.32	<0.0001*
C	24.50	1	24.50	119.25	<0.0001*
D	70.01	1	70.01	340.78	<0.0001*
A^2	0.087	1	0.087	0.42	0.5222
C^2	0.93	1	0.93	4.52	0.0450
D^2	0.55	1	0.55	2.67	0.1165
AC	1.02	1	1.02	4.97	0.0363
AD	0.52	1	0.52	2.54	0.1256
CD	0.19	1	0.19	0.91	0.3498
Residual	4.52	22	0.21	–	–
Total	151.47	31	–	–	–
* Significant at $p \le 0.05$					

Table 6

Statistical analysis (ANOVA) for noise level

Source	Sum of squares	DF	Mean square	F-value	Significant
Model	125.07	3	41.69	117.33	<0.0001*
D	93.39	1	93.39	262.83	<0.0001*
C	27.38	1	27.38	77.06	<0.0001*
E	4.30	1	4.30	12.11	0.0017*
Residual	9.95	28	0.36	–	–
Total	135.02	31	–	–	–
* Significant at $p \le 0.05$					

Model equations

Equations (1), (2) and (3) were developed equations that gave the functional relationship between the input variables no. of lightings (A), no. of windows (B), no. of workers (C), no. of machines (D) and age of machines (E) and output variables illumination (Y_1), temperature (Y_2) and noise level (Y_3).

Illumination (Lux) = $Y_1 Y_1$

$$Y_1 = 111.09 - 6.27A + 8.86B + 0.24A^2 - 1.21B^2 + 0.63AB \ (R^2 = 0.93)$$

$$Y_1 = 111.09 - 6.27A + 8.86B + 0.24A^2 - 1.21B^2 + 0.63AB \ (R^2 = 0.93) \tag{1}$$

Temperature (°C) = $Y_2 Y_2$

$$Y_2 = 26.49 - 0.09A - 0.62C - 0.16D + 0.00689A^2 + 0.04C^2 + 0.01D^2 + 0.02AC + $$
$$+0.01AD + 0.00833CD \qquad (R^2 = 0.97)$$

$$Y_2 = 26.49 - 0.09A - 0.62C - 0.16D + 0.00689A^2 + 0.04C^2 + 0.01D^2 + 0.02AC + $$
$$+0.01AD + 0.00833CD \qquad (R^2 = 0.97) \tag{2}$$

Noise Level (dBA) = $Y_3 Y_3$

$$Y_3 = 86.57 + 0.46D + 0.41C + 0.49E \qquad R^2 = 0.93$$

$$Y_3 = 86.57 + 0.46D + 0.41C + 0.49E \qquad R^2 = 0.93 \qquad (3)$$

The graphical model validation of the three parameters illumination, temperature and the noise level are shown in the Figs. 4, 5, and 6 below. The graphs on the RHS are plots of predicted values against actual values while those on the LHS are graphs the residual values against predicted values for each of the parameters. Therefore, from these results the adequacy and validity of the model can be checked to know if there exist a fuctional relationship between the inputs and outputs variables.

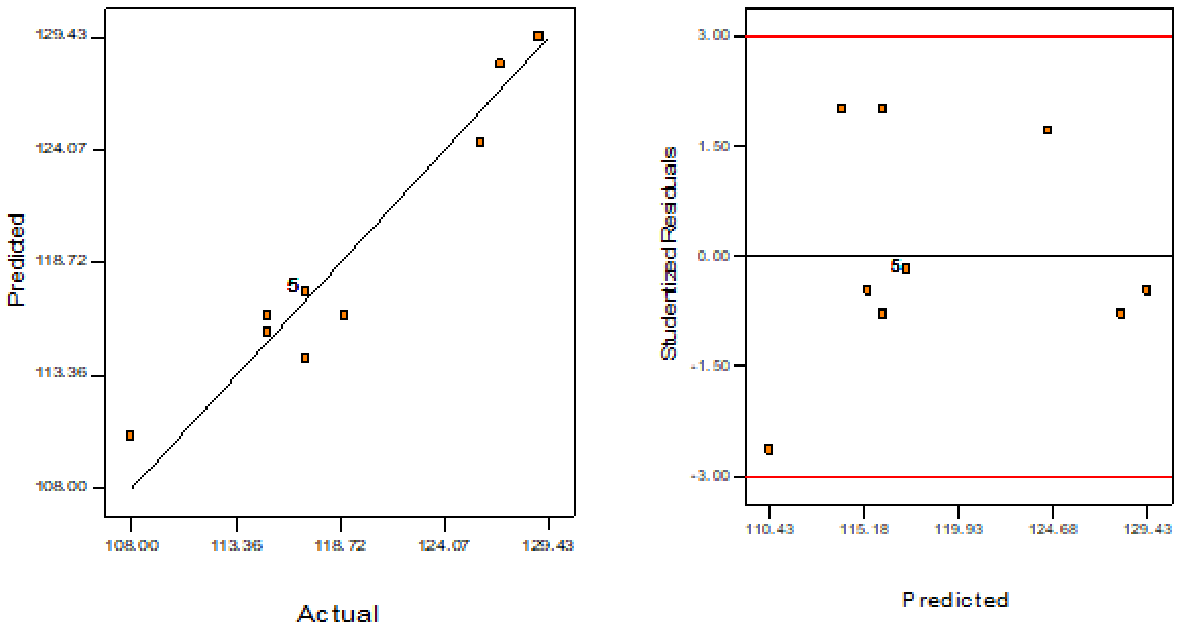


Fig. 4. Graphical model validation for illumination (predicted vs actual and residual vs predicted).
* RHS **:** Right Hand Side; LHS **:** Left Hand Side

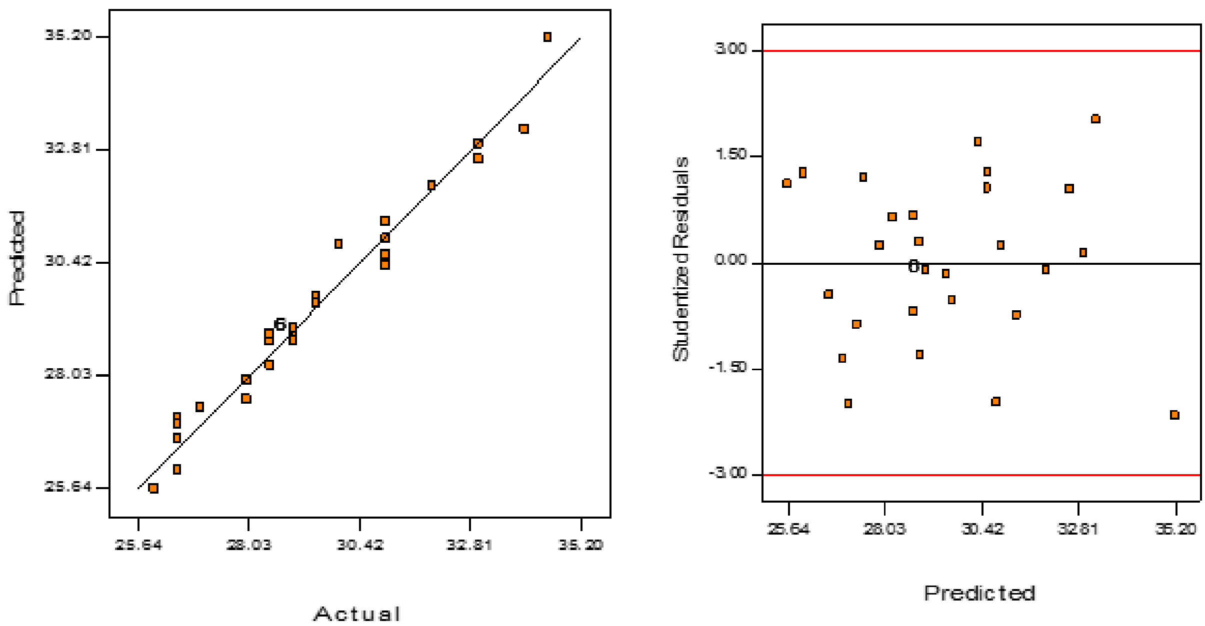
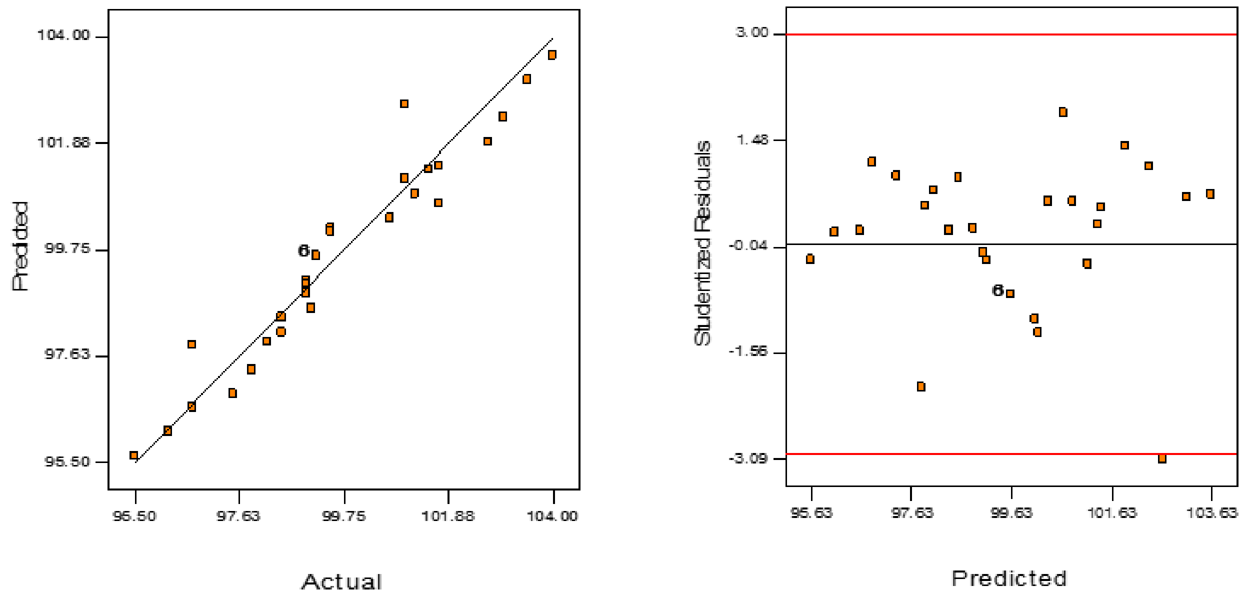


Fig. 5. Graphical model validation for temperature (predicted vs actual and residual vs predicted)



Fig, 6. Graphical model validation for noise (predicted vs actual and residual vs predicted)

Model adequacy check

The adequacy of the model was checked using a statistical tool called the coefficient of multiple determination. It reveals the total variability of the model developed. As shown in Table 7, (R^2) and (R^2_{Adj}) output values for all the parameters were high. It was also noticed that the values between (R^2) and (R^2_{Adj}) are relatively close with only slight differences of 0.0522 lux, 0.0122 °C and 0.0079 dBA for all model parameters. According to [10], relatively close values of these statistics indicated that the models developed were good. This statement holds for illumination, temperature and noise level.

Table 7

Model equation adequacy check

Output Statistics	Illumination (lux)	Temperature (℃)	Noise level (dBA)
R^2	0.9269	0.9702	0.9263
R^2_{Adj}	0.8747	0.9580	0.9184

Model validity check

The goal of model validation was to ensure the model developed solves the right problem and provide accurate information about the system being modeled to guarantee its suitability for use [11]. According to [12], this is expected of models to satisfy before it can be pronounce as good. Fig. 1, 2 and 3 showed the graphical model validation for illumination, temperature and noise levels. It can be inferred from the graphs that there are little differences between the (residual) values and predicted outputs. Also, the plots of the predicted against the actual values are approximately along a straight line, this therefore, satisfies the validity assumption as adopted by [13]. The statement holds for illumination, temperature and noise level.

Optimization results

Optimization was used to get the value of input parameters that will either maximize or minimize the output parameters. Tables 8, 9 and 10 showed the results of the optimization analysis. The goal was selected based on the importance of the responses illumination (Y_1), temperature (Y_2) and noise level(Y_3) concerning the study. After the analysis, the software selected one best combination of inputs; no. of lightings (A), no. of windows (B), no. of workers (C), no. of machines (D) and age of machines (E) for each output that best fulfils the goal of optimization.

Table 8

Optimization result for illumination

S/N	No of lightings (A)	No of windows (B)	Optimized output (Lux)	Desirability	Goal
1	13	5	124.431	0.921	Maximized*

Table 9

Optimization result for temperature

S/N	No of lightings (A)	No of workers (C)	No of machines (D)	Optimized output (℃)	Desirability	Goal
1	5.76	6.01	13.25	25.949	1.000	Minimized*
2	5.59	5.06	13.56	25.9129	1.000	Maximized
3	5.44	6.90	13.28	25.9958	1.000	Maximized
4	5.05	6.91	13.05	25.8320	1.000	Maximized
5	5.01	7.63	13.08	25.9665	1.000	Maximized

Table 10

Optimization results for noise Level

S/N	No of lightings (A)	Noof workers (C)	Age of machines(D)	Optimized output (dBA)	Desirability	Goal
1	10.04	5.00	5.00	95.6438	0.983	Minimized*
2	10.00	5.00	5.04	95.6438	0.983	Maximized
3	10.00	5.07	5.00	95.6532	0.982	Maximized
4	10.00	5.01	5.07	95.6628	0.981	Maximized
5	10.00	5.41	5.00	95.7928	0.966	Maximized

The optimization combinations for each output were ranked according to desirability (0–1). The closer the desirability to one, the better [14, 15]. Therefore, illumination (maximized) from 115.93 lux to 124.43 lux, temperature (minimized) from 115.93 ºC to 124.43 ºC and noise level (minimized) from 99.29 dBA to 95.64 dBA with desirability values of 0.921, 1.000 and 0.983, respectively**.**

Conclusions

The study on safety parameters for workplace ergonomics of a steel industry in Ilorin metropolis, revealed that the work environment understudy has a mean temperature value of 30.87 °C, illumination value of 115.93 lux and noise level value of 99.29 dBA. Three (3) model equations that gave functional relationships between inputs (no. of lightings, no. of windows, no. of workers, no. of machines, and age of machines) and output (illumination, temperature and noise Level) were developed. The adequacy and validity checks revealed that all developed model equations could be used as reliable tools for estimating, predicting and conducting analysis of the process. The best-optimized results were selected based on desirability (0-1), illumination (maximized), temperature (minimized) and noise level (minimized) had desirability values of 0.921, 1.000 and 0.983, respectively. The results revealed that the environmental parameters studied were not in conformation with the OSHA standard, serving as potential health risks to the workers.

Recommendations

1. The developed model equations can be used in other factories to evaluate the workplace hazards and predict the adequacy of compliance.
2. The Nigerian mines and steel development and other regulatory bodies must ensure organizations and factories are visited routinely to monitor workplace safety compliance.
3. Meaningful engagement with safety institutions necessary in order to conduct a review safety practices and draw up new code of standards.

4. Punitive measures and sanctions from the agency of government and monitoring committee necessary in order to instill safe work practices and discourage violations.

5. Comprehensive advocacy and workplace safety campaigns should be done regularly and be encouraged at organizational level.

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