A Mathematical Model for Operating Cost of an Industrial Air Conditioning Plant

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Abstract: The creation of cold environment has relevance in a significant number of areas of human life, for instance the food processing field, the air-conditioning sector, the preservation of pharmaceutical products, the preservation of blood and storage of vaccines and drug in hospital. This paper presents a mathematical model for predicting the operating cost of an industrial air conditioning plant. Mathematical equations were developed from experimental data collected from Air Conditioning Servicing Company in Lagos. The empirical equation between operating cost and period was governed by polynomial function of order 4 in nature. The coefficient of determination, R^2 for operating cost empirical equation is 0.9552. The empirical equation was used to predict operating cost and the graphical comparison of experimental and predicted cost showed negligible difference with average percentage error of 2%. The predicted costs were subjected to further investigation by performing t-test analysis at 5% and 1% significant level. The t-test analysis obtained from the different models and experimental results revealed that there is no significant difference experimental and simulated result at 95% and 99% confidence limit; hence the models are reliable. The result from this paper is expected to assist in developing models that can be used in adequate preparation for an operating cost for industrial air conditioning plant for a period of time. The mathematical models for predicting cost at any time save time, money and reliable, for easy maintenance, reliability and accuracy.

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1. Introduction

An air conditioner is an appliance, system, or mechanism designed to extract heat from an area via a refrigeration cycle. In construction, a complete system of Heating, Ventilation, and Air Conditioning is referred to as "HVAC." Its purpose, in a building or an automobile, is to provide comfort during either hot or cold weather, (United State Department of Energy, 2006). Early commercial applications of air conditioning were manufactured to cool air for processing industry rather than personal comfort. In 1902 the first modern electrical air conditioning was invented by Willis Haviland Carrier in Syracuse, NY. It was designed to improve manufacturing process control in a printing plant, his invention controlled not only temperature but also humidity, (Jone, 2007; Arora and Domkundwar, 2006).

The Carrier Air Conditioning Company of America was founded to meet rising demand. Over time air conditioning came to be used to improve comfort in homes and automobiles, (Richard, 2004). Air conditioning became established in commercial use, in textile mills where temperature and humidity control are absolutely essential, that it transferred into homes on any large scale, (Russell (2001). Both commercial public transport vehicles and private cars are now routinely fitted with systems to filter, regulate and even purify the air. With the modern lifestyle in the Western world meaning that more time is spent in vehicles, the need has increased to make the environment in those vehicles more comfortable, (Schmidt, 1983; Mario, 1993).

Cost is first relevant factor in designing and using of an air conditioning plant. This is more importance in industrial air conditioning because the profit is the primary consideration in industrial, engineer must put into consideration the cost of air conditioning plant, operating cost, energy cost and maintenance cost. If experiments were used to perform the parametric study effects of one key parameter on the overall system performance would normally require several cooling seasons and hence years to establish a conclusion. Also, it is extremely difficult to keep the performance of the system components to be constant over the entire experimental period as the components deteriorate with time. Therefore, it is difficult and expensive to carry out experiments to investigate the influence of all the key parameter. To improve the system design of an air conditioning plant system, a parametric study is required using predictive model to investigate the influence of key parameters on the overall system performance. Therefore there is need to develop a mathematical model for evaluating operating cost of an industrial air conditioning plant.

2. Material and Methods

Structure questionnaire was employed in collecting data from an air conditioning service company. The structure questionnaire was filled by the maintenance manager and sale manager. The trend line equations were developed for maintenance and energy cost of an industrial air conditioning plant is based on descriptive statistics. The method makes it possible to quantify in monetary term, most of the aspect that distinguish the technologies being compared. Predictive analysis is an area of statistical analysis that deals with extracting information from data and using it to predict future trends and behavior patterns. The core of predictive analytics relies on capturing relationships between explanatory variables and the predicted variables from past occurrences, and exploiting it to predict future outcomes.

Regression models are the most importance role of predictive analytics. The focus lies on establishing a mathematical equation as a model to represent the interactions between the different variables in consideration. Depending on the situation, there is a wide variety of models- that can be applied while performing predictive analysis.

The t-test is used to calculate the significance of observed differences between the mean of two samples. T-value is calculated t, and then compares that value to the critical t-value in a table for a given degree of freedom. To calculate t-value, first calculate the mean ($\bar{x}$) and the simple variance (s^2) of each sample.

(i) First, calculate the variance in each of the sample

Sample variance: $$s^2 = \frac{\sum (x - \bar{x})^2}{n-1} \quad \ldots(1)$$

Sample mean: $$\bar{x} = \sum \frac{x}{n} \quad \ldots(2)$$

Sample size: n= number of observation in sample
N= number of observation in all samples being compared

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(ii) Second, calculate the t-value

$$t = \frac{|x_1 - x_2|}{\sqrt{\frac{s_1^{\,2}}{n_1}} + \sqrt{\frac{s_2^{\,2}}{n_2}}} \quad \ldots(3)$$

(iii) Third, calculate the degree of freedom

Calculate the degree of freedom (df) by adding the sample of both mean (n) which leads to overall sample size (N).

$$N = n_1 + n_2 \text{ and } df = N - 1 \quad \ldots(4)$$

(iv) Decision: Null hypothesis that there is no significant difference will be accepted if t-value is less than t-critical value and reject alternative hypothesis that there is significant difference or vice versa.

Operating cost per annum is obtained as sum of maintenance and energy cost. Energy cost is estimated as amount of money spent on electricity (electrical) and diesel in running the plant per annum. Maintenance cost is the total money spent on routine, preventive and breakdown maintenance per annum.

3. Results

The average data obtained for operating cost and energy cost per month for industrial air conditioning plant are presented in Figure 1 and 2 respectively

3.1Determination Total Trendline Equation

Mathematical equation is established as a model to represent the interactions between the maintenance cost, energy cost and operating cost with respect to period are shown in Figures 1 and 2 respectively

4. Analysis and Discussions

The line of best fit for the points in Figures 1 and 2 follow a polynomial law given by models shown in Figure 3 for operating cost, y represents cost and x represents period (month), increase in the period leads to corresponding increase in Operating cost per month. R^2 is coefficient of determination which explains percentage changes on cost whenever period is changed for all the models.

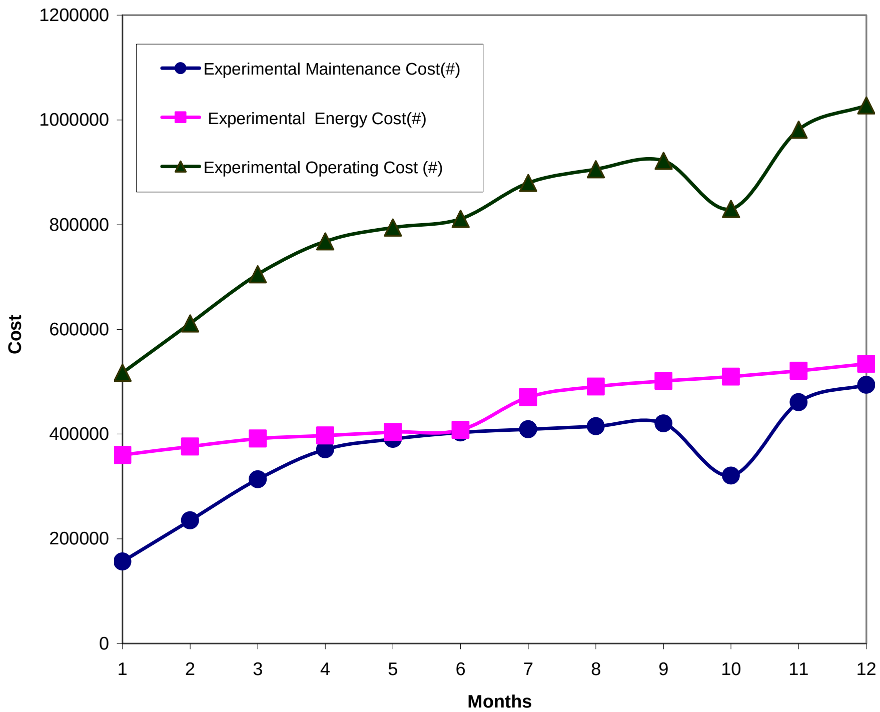

Figure 1 Graph of Operating Cost against Period

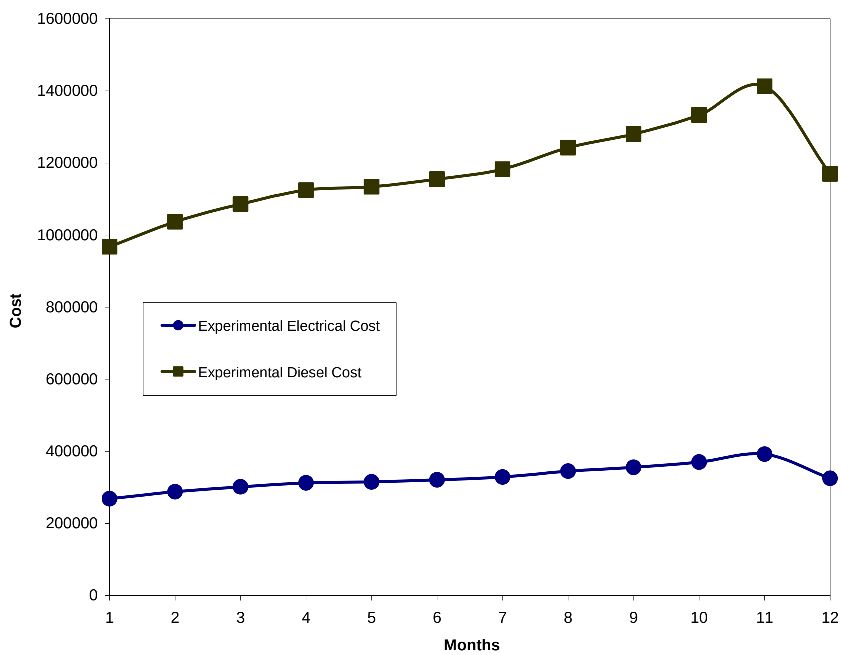

Figure 2 **Graph of Energy Cost against Period**

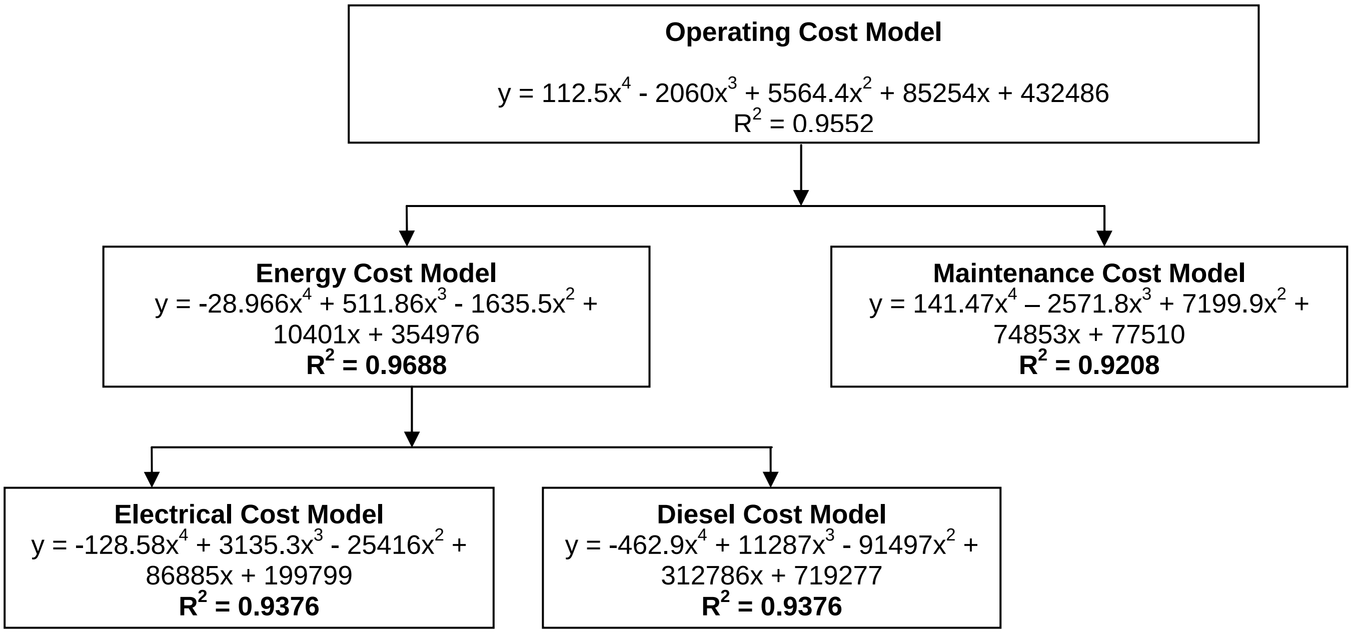

Figure 3: Flow chart showing summary of developed models with corresponding R^2

Figures 4 – 8 however show the graphical comparisons of experimental and model results. It can then be deduced from Figures 4 – 8 that, there is negligible difference between experimental and simulated result of operating cost, maintenance cost, energy cost, electrical cost and diesel cost. It can also be observed that the cost increases as the period increases. The models are further investigated by using statistical test known as t-test.

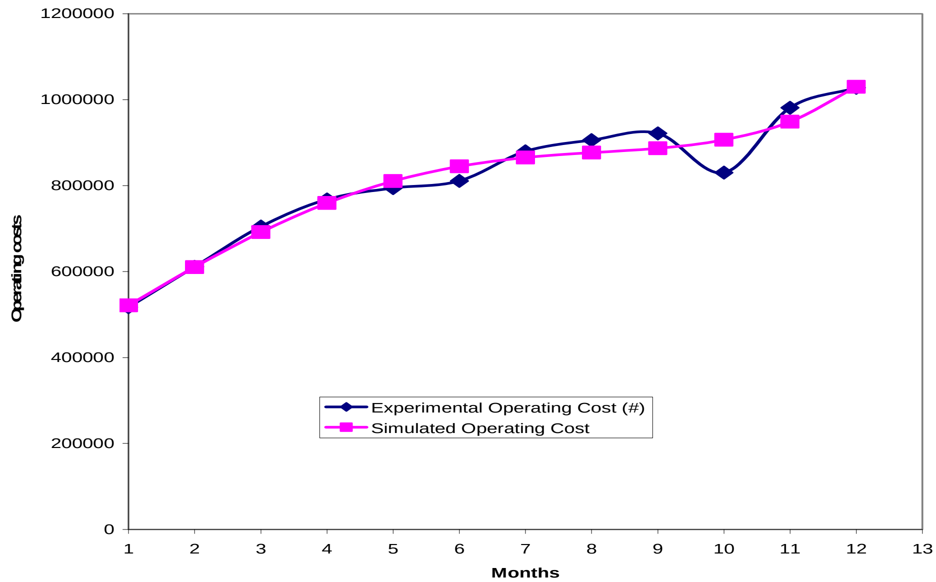

Figure 4 graphical comparisons of experimental and simulated operating results

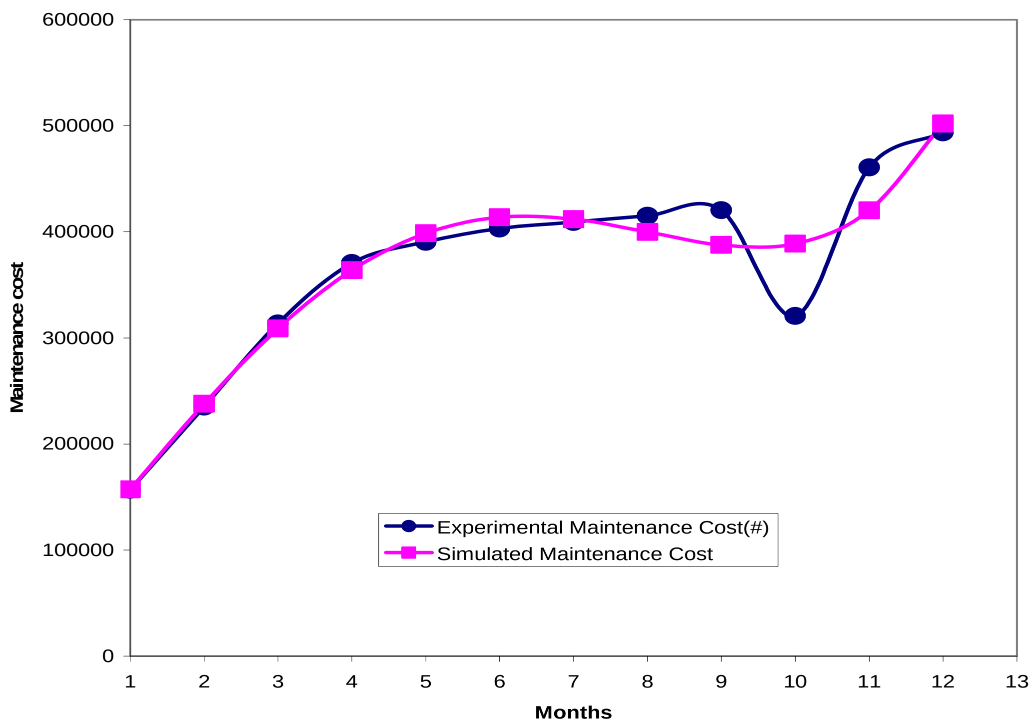

Figure 5 graphical comparisons of experimental and simulated maintenance results

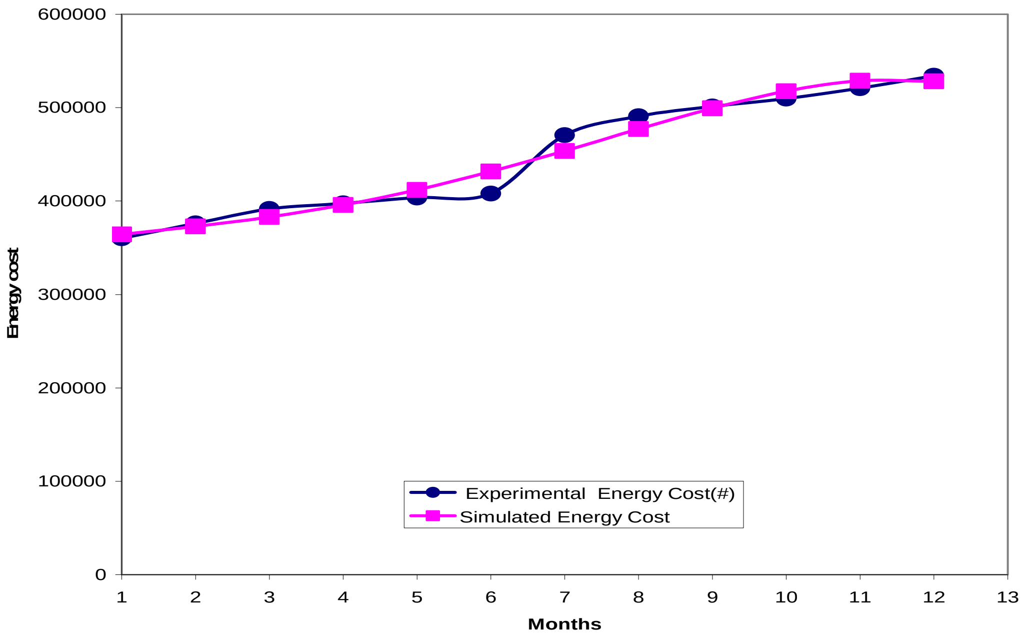

Figure 6 graphical comparisons of experimental and simulated energy results

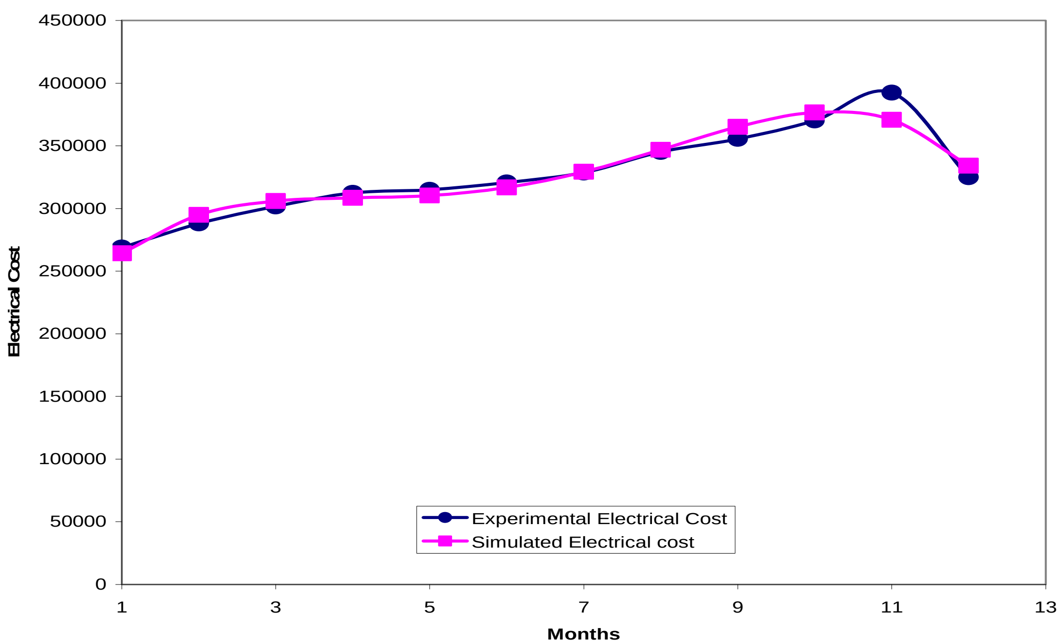

Figure 7 graphical comparisons of experimental and simulated electrical results

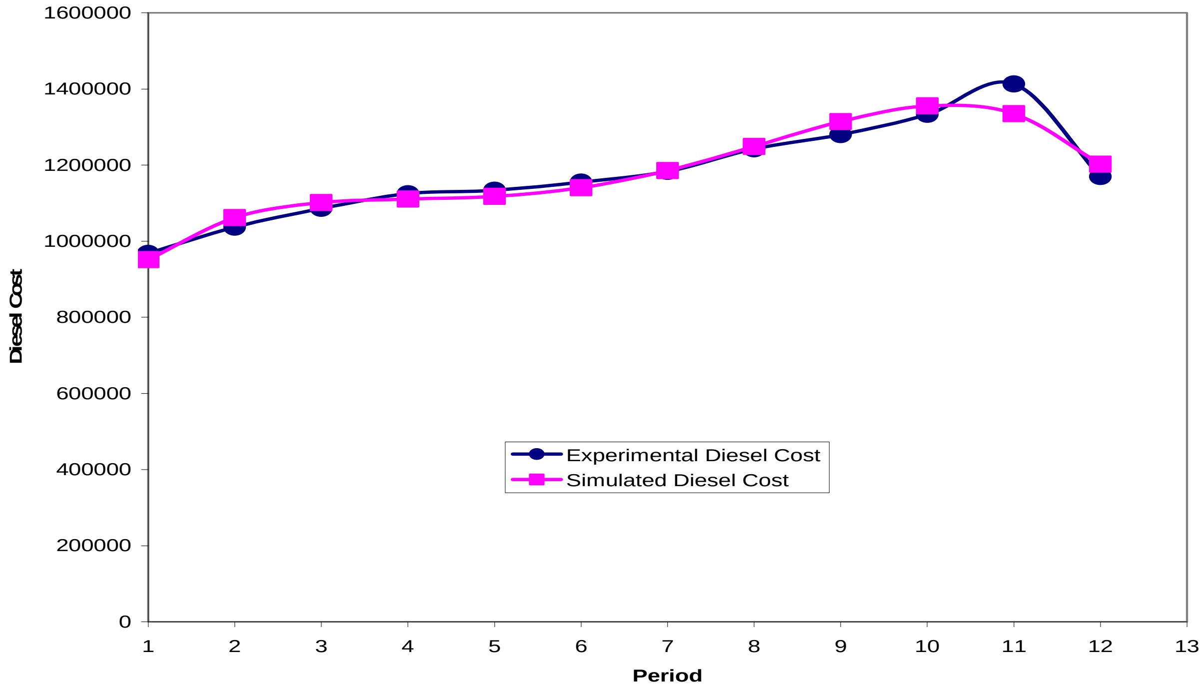

Figure 8 graphical comparisons of experimental and simulated diesel results

4.1 T-test

Summary of T-test performed for each model at degree of freedom of 22 and 95% confidence limit for both P(T<=tcal) one-tail = 0.499854398 and P(T<=tcal) two-tail = 0.999708797

Table 1 revealed at the significant level of 0.05 or 0.01 is customary. 5% means there are about 5 chances in 100 that we would reject the hypothesis when it should be accepted. From the test above the probability of any experiment can be viewed as total area under the normal curve between any two coordinate t-experimental and t-simulated result, when t-stat value is less than t-critical value is still within the acceptable region, hence it is accepted that there is no significant difference between experimental and model result otherwise there is significant difference in the results

Table 1 Summary of T-test for Comparing Experimental and Simulated results Assuming Equal Variances

S/N	Descriptions	t Stat	t Critical one-tail	t Critical two-tail
1	Operating Cost Model	0.000197651	1.717144187	2.073875294
2	Energy Cost Model	0.000122673	1.710882316	2.063898137
3	Maintenance Cost Model	-0.001091868	1.717144187	2.073875294
4	Electrical Cost Model	0.000978245	1.717144187	2.073875294
5	Diesel Cost Model	0.002337561	1.717144187	2.073875294

At significant level of 5%:
for operating cost model, t-stat = 0.000197651,
for energy cost model, t-stat = 0.000122673,
for maintenance cost model, t-stat = -0.001091868,
for electrical cost model, t-stat = 0.000978245 and
for diesel cost model, t-stat = 0.002337561.

For P (T<=tcal) one-tail is 0.499854398 and t-critical value is 1.717144187.

Also for P(T<=tcal) two tails is 0.999708797 and t-critical value is 2.073875294.

It is evident from Table 1 that t-stat values for all the models are less than t-critical value for both one tail and two tails, therefore, it is affirmed that the mathematical model developed for operating cost model, energy cost model, electrical cost model, maintenance cost model and diesel cost model are reliable for predicting it at any period since there is no significant difference between the simulated and experimental result.

5. Conclusions

Energy is an indispensable commodity for the economic growth, proper energy management should be maintained and source for alternative energy source such as solar energy may be required. The cost of operating an industrial air conditioning plant increases as the period increases; It was revealed that there is no significant difference between the experimental and simulated result obtained from developed model at 5% and 1% significant level for all the models developed; hence, the predictive models are reliable. Finally, the mathematical models for predicting cost at any time save time, money and reliable for easy maintenance, reliability and accuracy.

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