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Modeling of the Operational Parameters on the Performance of an Air Conditioning System

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ABSTRACT

Heat and moisture are removed from occupied spaces by air conditioning systems. Air conditioners regulate moisture and temperature, and improve air quality. Human efficiency is dramatically boosted and worker's efficiency is affected by their work environment. Human being is more comfortable and productive with air conditioning. After a few years of excellent operation, the system began to fail, resulting in numerous resident complaints. The goal of this study is to establish operational characteristic models for an air conditioning system's performance in order to fulfill future client requirements. The inlet and output temperatures as a function of local time were measured for the LSBLG 1200/MCF model central water chiller air conditioning system. The COP and EER curves were examined. MiniTAB 16.0 was used to establish the characteristic curves and models, according to the findings. The regression models are statistically significant at 97.7 percent and 91.1 percent for p-value less than 0.05 and R^2, respectively. The COP and EER values were calculated, and it was determined that the best cooling occurred between 1 and 3 p.m. The chiller and cooling tower achieve maximum coefficients of performance (COP) of 52 and 20, respectively. The chiller and cooling tower have EER ratings of 177 and 68, respectively. Regression analysis is used to develop models that characterize the statistical relationship between operational parameters such as input and outlet temperatures as a function of local time and response variables such as COP and EER. The performance of the system can be monitored using existing models.

Keywords: Modeling, operational parameters, performance, and air conditioning system.

INTRODUCTION

Air conditioners are a vital device in the house or office for many reasons. Air conditioners not only regulate moisture and temperature, but also improve air quality. Air conditioners bring filtered, fresh air into a home [1-4]. This clean air is free of exterior dirt particles, dust, and even bacteria that enter through the doors and windows [5-8]. This filtered air creates a healthier, cleaner environment that is ideal for children, families, and commercial settings where large groups of people work together for long periods of time [10-11]. Hot weather causes weariness more quickly. The same is true in hot and humid climates, which is why commercial property owners should invest in an air conditioner [12-14]. People spend between 80% and 90% of their time indoors, and the interior environment has a significant impact on human health and productivity [1-5]. Air conditioning systems have been employed in a variety of locations throughout the world to provide occupants with thermal comfort and acceptable indoor air quality (IAQ) [3]. [4], discovered an increase in the occurrence of sick building syndrome (SBS) of between 30% and 98%. SBS is a warning sign for interior environment problems associated with air conditioning systems and legionnaires' disease has been associated with death in air-conditioned buildings. Since the 1970s, buildings have become more airtight and incorporate a greater amount of insulation materials to decrease energy loss via the building envelope. In air-conditioning systems, fresh air is restricted to reduce energy use in an air-tight building [5]. Since 1994, the automobile industry has used R134a as a regular substitute for CFC12. Due to the fluorine concentration of this refrigerant, it has a very high Global Warming Potential. There is a need to identify R134a substitutes under the Kyoto and Montreal Protocols. [6], investigated the performance of an automotive R134a air conditioning system with a variable capacity compressor. Simulations were run to determine the effect of design parameters on compressor speed, return air to the evaporator, and condensing air temperatures. According to a research of a vehicle air conditioning system employing R134a and fixed and variable capacity compressors, the variable speed compressor typically has a higher coefficient of performance (COP) than the fixed speed compressor. It also costs more because the cooling capacity is reduced, while the working temperature is increased [7]. Alternative refrigerant technologies were discussed by [8]. R152a were used in place of R134a with no modifications. It operates similarly but cools more efficiently. R152a has a tenfold lower global warming potential than R134A, which is an environmental benefit. [9], used a variety of hydrocarbons to imitate the functioning of automotive air cooling systems and found that R152a and R270 systems perform better than R134a systems. [10], examined the performance of R1234yf, R134a, and R290 in an open piston compressor used in car air conditioning under a variety of operating circumstances. The compressor and volumetric efficiency of R290 were found to be significantly improved. [10], conducted experimental investigations using a vapor compression device and R1234yf has a cooling capacity approximately 9% less than R134a.

[14-19], conducted an experimental study on a variable displacement compressor-equipped automobile air conditioning system and found that R1234yf systems perform less well than R134a systems when cooling capacity is same. [11], conducted a quick performance comparison of R1234yf and R134a in a vehicle bench tester and concluded that R1234yf had a poorer coefficient of performance and cooling capacity than R134a by 2.7 percent and 4%, respectively. [15], investigated the influence of condenser subcooling on the performance of an air conditioning system using R134a or R1234yf. Due to the thermodynamic differences between R1234yf and R134a, it was established that the COP of the system operating with R1234yf can benefit more from condenser subcooling. Poor ventilation rates and the presence of multiple synthetic chemicals contribute to indoor particle pollution. This is considered to be a significant contributor to compound hypersensitivity in the environment; nonetheless, it is encouraging that some comfortable and healthful air-conditioning solutions have been developed in recent years. This study is to evaluate the performance of the entire AC Systems with a view to developing its performance characteristic curve and models.

METHODOLOGY

The investigation of AC system operation was carried out on an LSBLG 1200/ MCF model central water chiller air conditioning system. The performance of two AC samples from various manufacturers and models was examined.

Operational Principle of a Water Chiller System

A typical water chiller system includes the following components: a pump, cooling coils, expansion tank, and pipe valves and controls. The thermostats regulate the temperature in the cooled areas. This is the point at which the chilled water absorbs heat from the air passing over the air handling coil or fan coil devices. Water runs through the condenser of a water cooled chiller to cool the hot discharge gas to condensing temperature. In the majority of chiller applications, a water-cooled condenser is used in conjunction with a cooling tower. Water is constantly fed to the cooling tower through the use of water pipes. Fig 1.0 illustrates Schematic diagram displaying the operation of a water chiller system.

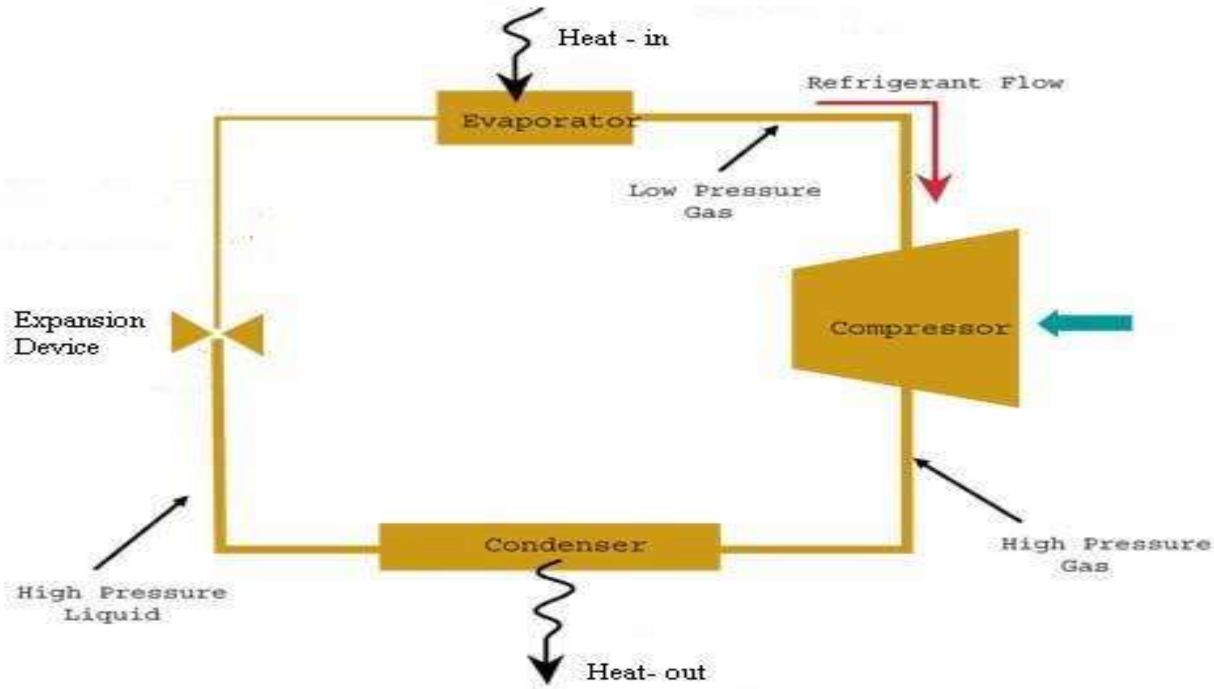

Fig. 1. Schematic illustration of the water chiller system's functioning concept.

The operating parameters of the AC system, such as the temperature of the LSBLG 1200/MCF model chiller, the temperature of the cooling tower, and the temperature of the lubricating oil, were recorded for 8 hours at one-hour intervals using the in-built data display unit. The AC system's noise level was measured using a sound level meter during a period of eight hours at one-hour intervals. The results are presented using profiles in order to develop characteristic curves and models for the air conditioning system. The performance parameters such as COP and EER were evaluated.

Performance Evaluation

The Coefficient of Performance, COP, Energy Efficiency Ratio, EER, and Seasonal Energy Efficiency Ratio, SEER ratings are used for performance evaluation of air conditioners. A greater ratio indicates a more efficient system and serves as the basis for determining an air conditioners star rating, and when purchasing an air conditioner, a model with a high efficiency rating is chosen. The coefficient of performance of a refrigerator is the amount of heat removed from the cold reservoir divided by the amount of work, W, required to remove the heat as expressed in equation (1)

$$COP = \frac{Q_{cold}}{W} \qquad (1)$$

The refrigerator is more effective and efficient when it can remove more heat Qcold from the interior of the refrigerator for a given amount of effort. Because the first law of thermodynamics must apply in this instance as well, eqn. (2) is used to represent the expression.

$$COP = \frac{Q_{cold}}{W} = \frac{Q_{cold}}{Q_{hot} - Q_{cold}} \quad (2)$$

It can be analyzed that for an ideal refrigerator, COP is given in eqn.(3)

$$COP = \frac{T_{cold}}{T_{hot} - T_{cold}} \quad (3)$$

These equations are applicable to an air conditioner, which operates in a manner similar to that of a refrigerator. The Coefficient of Performance is a ratio used to determine the efficiency of heating and cooling systems as expressed in eqn.(3)

$$\mathrm{COP} = \frac{\text{Output heating or cooling (Wh)}}{\text{Input electrical energy (Wh)}} \quad (3)$$

Energy Efficiency Ratio, EER is suitable for cooling system evaluation. EER and COP are related in the form shown in eqn (4

$$\mathrm{EER} = \mathrm{COP} * 3.41 \quad (4)$$

Energy Efficiency Ratio is a metric used to analyze the performance of cooling systems as presented in eqns, (5 & 6)

$$\mathrm{EER} = \frac{\text{Output cooling (BTUh)}}{\text{Input electrical energy (Wh)}} \quad (5)$$

$$\mathrm{EER} = 1.12 * \mathrm{SEER} - 0.02 * \mathrm{SEER}^2 \quad (6)$$

Where SEER is Seasonal Energy Efficiency Ratio, It is used to represent the relative amount of energy needed to achieve a certain cooling output and the expected overall performance for a typical year's weather in a given location. It is calculated with the same indoor temperature as inside, but over a range of outside temperatures from 18 °C to 40°C as shown in eqn.(7)

$$\mathrm{SEER} = \frac{\left(1.12 - \sqrt{(1.2544 - 0.08 * \mathrm{EER})}\right)}{0.04} \quad (7)$$

Development of Characteristic Curve and Model

The plots of the measured performance parameters were generated after obtaining the required parameters. The measured performance parameters were then fitted into regression equations using the MiniTAB 16.0 Scientific package to develop characteristic models of the performance parameters of each component attribute at any time. Additionally, the established characteristic models for each component would be utilized to forecast the component's performance.

RESULTS AND DISCUSSION

LSBLG 1200/MF water chilled air conditioning system was evaluated, Characteristics Curves and model equations were developed.

Characteristics Curves

The performance parameter charts were constructed, after acquiring the critical parameters from the LSBLG 1200/MF water chilled air conditioning system. Figures 2.0, 3.0 and 4.0 illustrate the influence of outlet chiller temperature on the COP and EER. The results indicate that as the outflow temperature of the chiller cooling water increases, the COP and EER increase as well. This means that the air conditioner performs optimally at lower chiller and cooling water outlet temperatures.

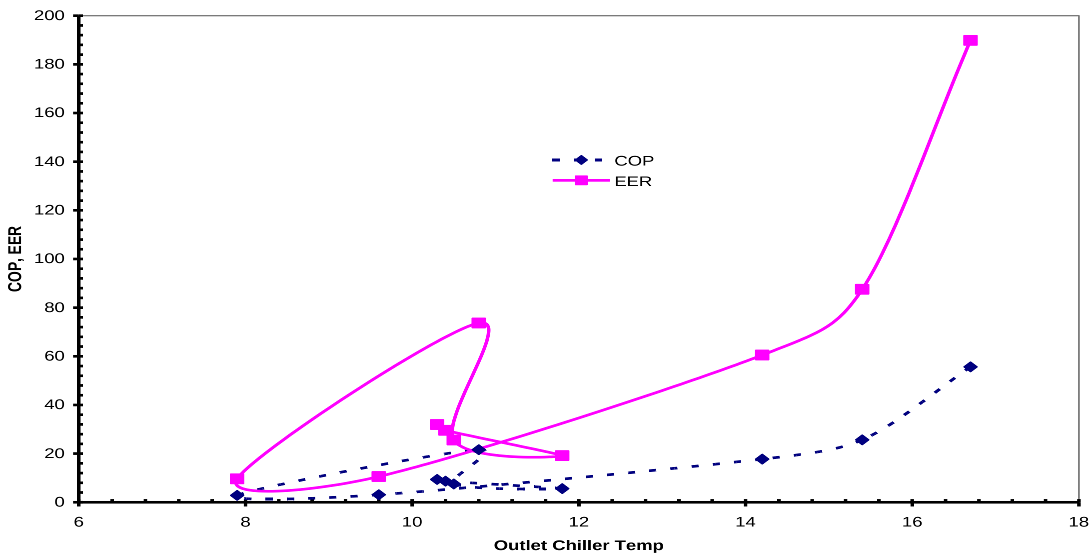

Fig. 2. Plot of COP and EER against Outlet Chiller Temperature on 28/05/2018

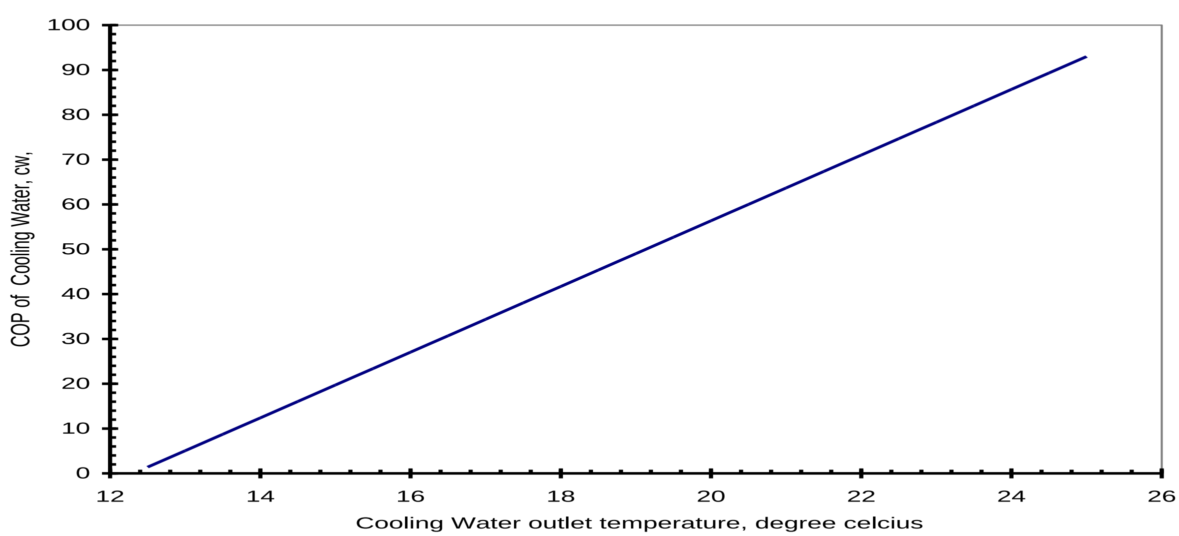

Fig. 3. Plot of COP of Cooling Water against Cooling Water outlet temperature

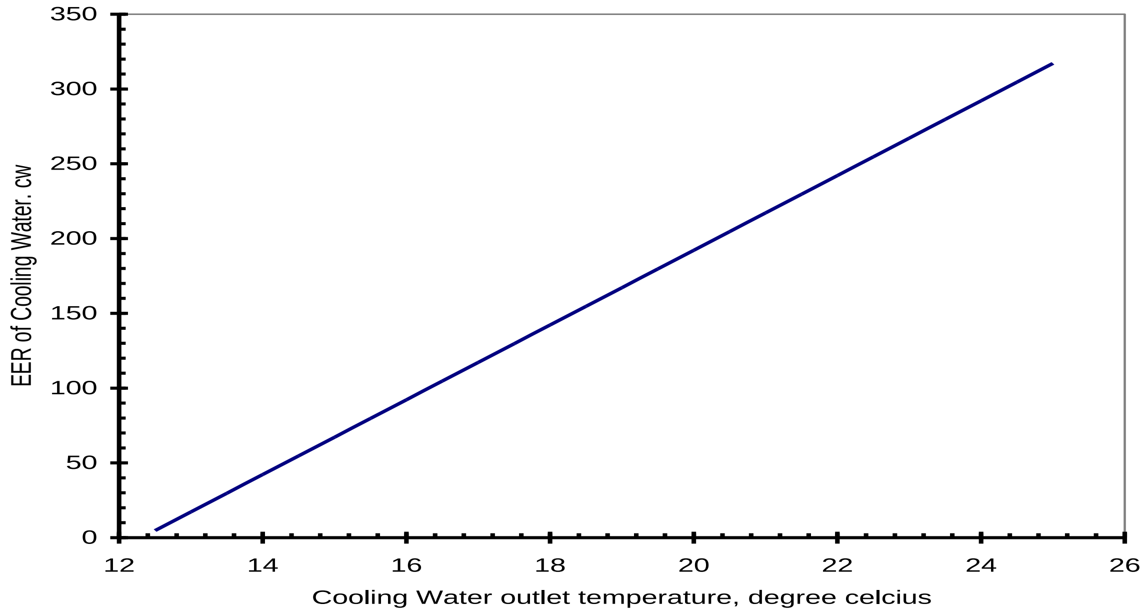

Fig. 4. Plot of EER of Cooling Water against Cooling Water outlet temperature

Figures 5 and 6 illustrate the influence of outlet cooling tower temperature on the COP and EER of cooling tower. The findings show that cooling tower performance is proportional to the temperature at the cooling tower outlet.

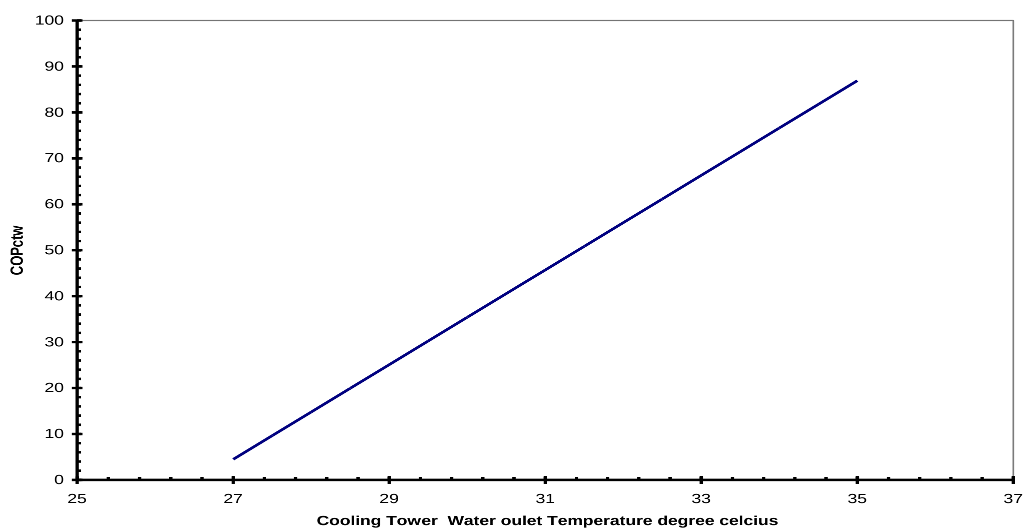

Fig. 5 Plot of COP of Cooling Tower against Outlet Cooling Tower Temperature

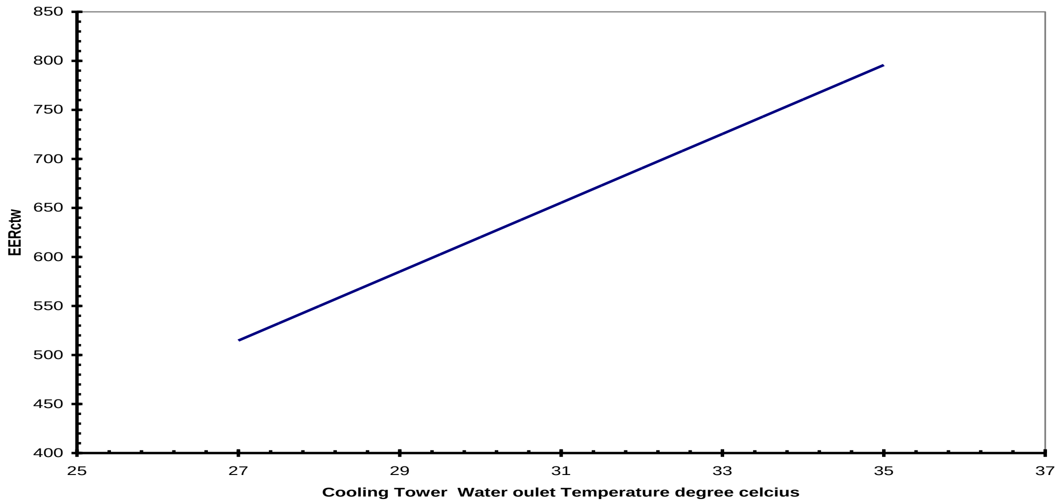

Fig. 6. Plot of EER of Cooling Tower against Outlet Cooling Tower Temperature

Figures 7 and 8 illustrate the impacts of local time on the COP and EER of cooling water towers, ct, and cooling water, cw. The findings show that the cooling tower's COP and EER behave dynamically when local time changes, which is related to the dynamic nature of climatic weather factors.

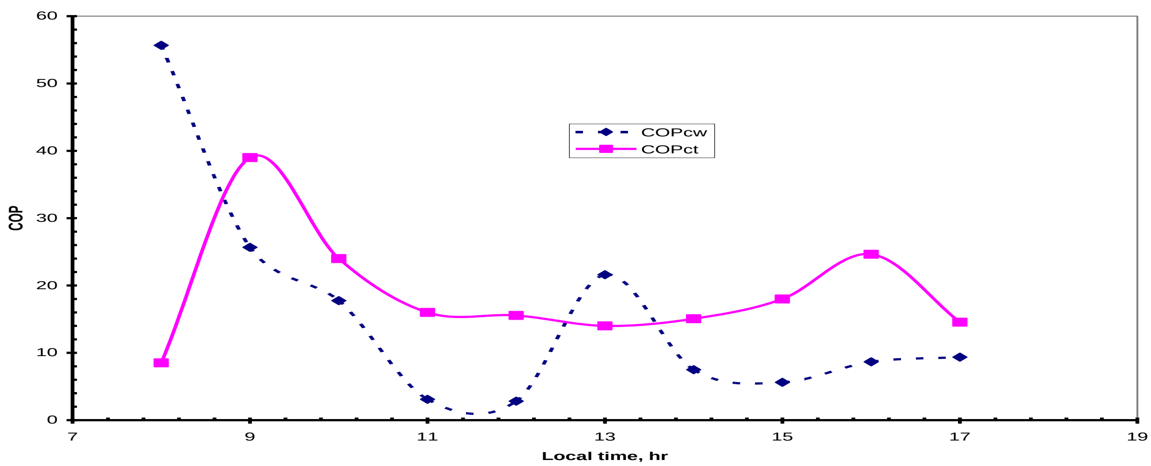

Fig. 7.Plot of COP of Cooling water tower, ct and cooling water, cw against local time

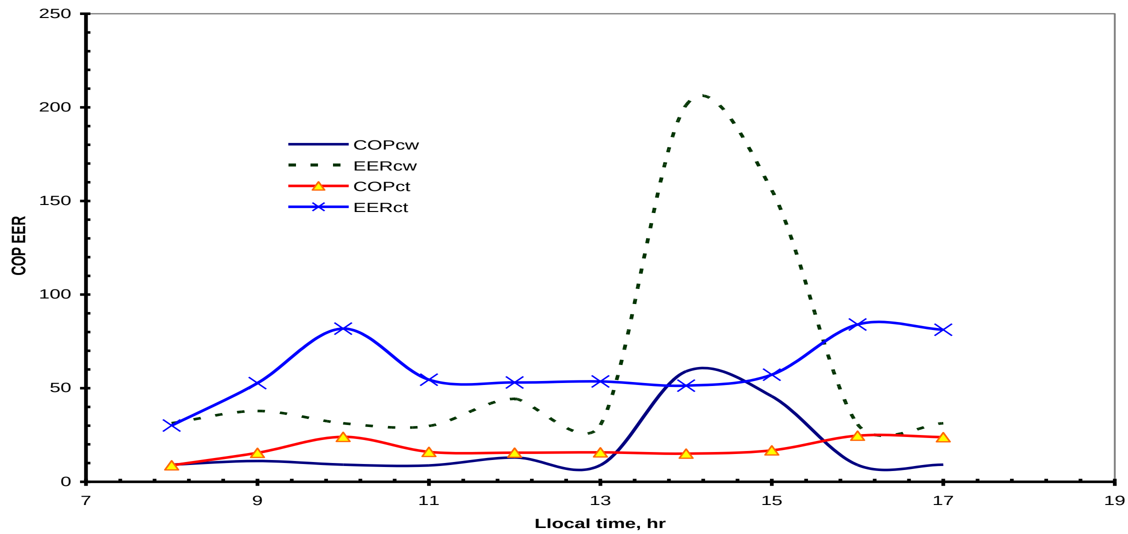

Fig. 8. Plot of COP, EER of Cooling water tower, ct and cooling water, cw against local time

Fig. 9.depicts a plot of noise level, in decibels against local time at different days. Figure 10 illustrates the typical curves of the Chiller's water entry and outflow temperatures as a function of local time. Figure 11 illustrates the characteristic curves of the cooling tower water entry and output temperatures as a function of local time. Figure 12 illustrates the characteristic curves for relative humidity and noise level as a function of local time. The graphs show how local time affects operating functional characteristics such noise, humidity, chiller water entry and outlet temperatures, and cooling tower water inlet and outlet temperatures. The results demonstrate that these parameters are dynamic as a function of local time. The dynamic nature of meteorological conditions dictates these behaviours.

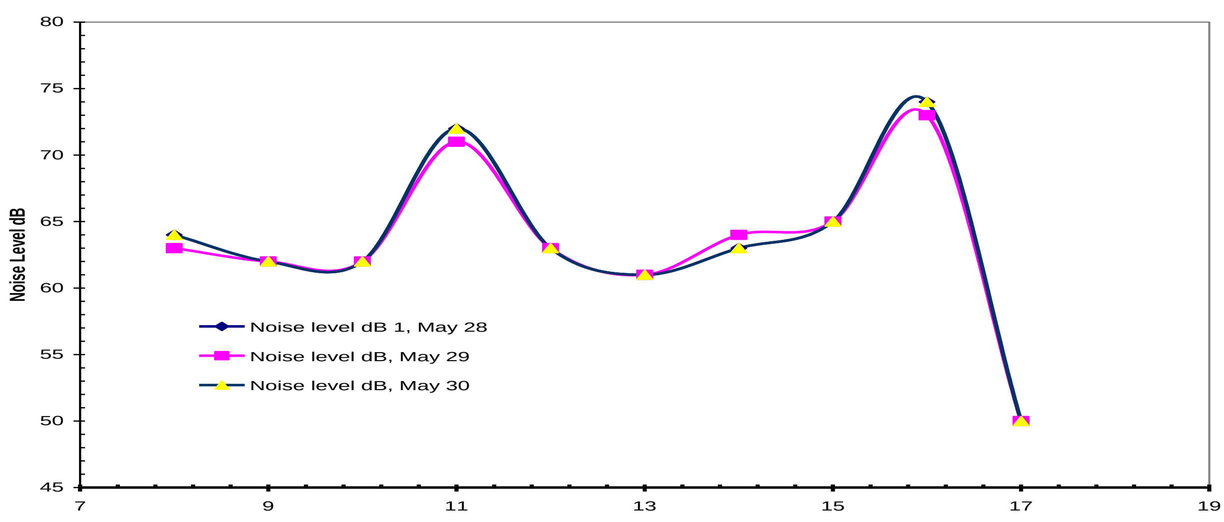

Fig. 9 Plot of Noise level, dB against local time at different days

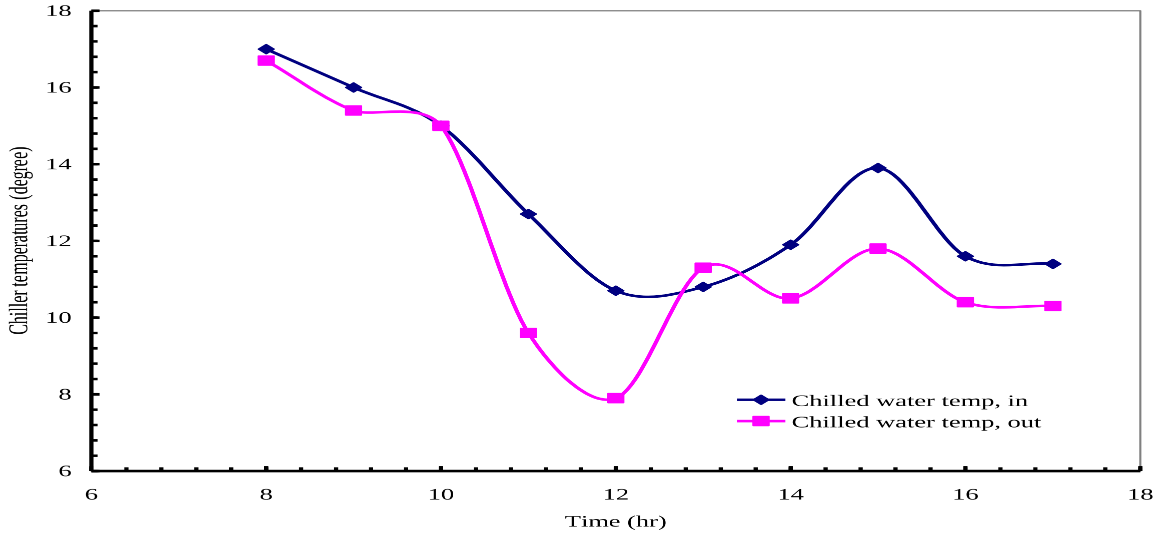

Fig. 10 Plot of Chiller water inlet and outlet temperatures against local time

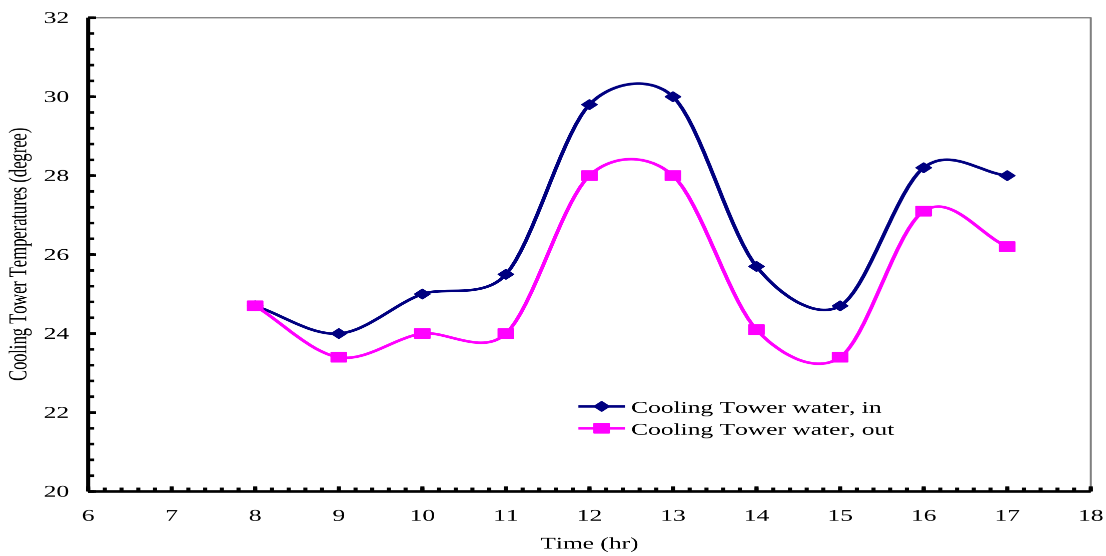

Fig. 11 Plot of Cooling Tower water entry and exit temperatures against local time

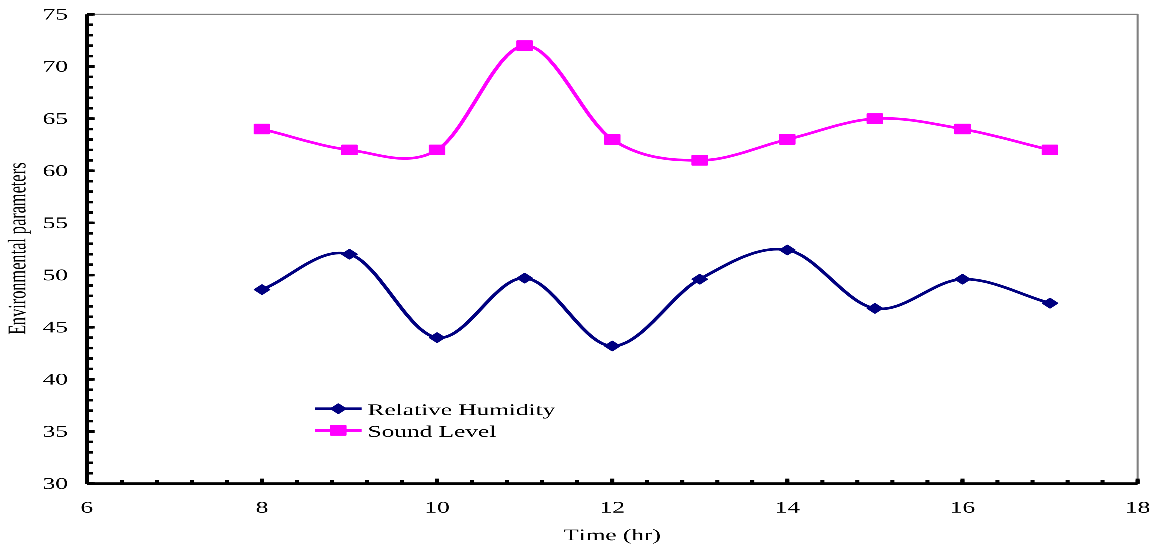

Fig. 12 Plot of Relative humidity and Noise level against local time

The characteristics curves indicate that the tendency of the curves grew as the local time increased; indicating that the thermal influence in the surrounding increased and more heat was generated in the room, resulting in increased heat extraction. The air conditioner extracted the most heat, between 1:00 and 2:00 p.m. This explains why heat extraction is reduced when the thermal influence on the surrounding environment is reduced and the room generates less heat.

Characteristics Models

The characteristics models are produced for COP chiller (Y1), EER chiller (Y2), COP cooling tower (Y3), and EER cooling tower (Y4) as presented in eqns (8 - 11).

Coefficient of Performance of Chiller, COPc

Characteristic equation model of Coefficient of Performance of Chiller as function of time, chiller water inlet and outlet temperatures is shown in eqn. (8)

The regression equation is

$Y_1 = 16.2 - 0.177t - 6.94\,Xi + 7.33\,Xo$ (8)

Where Y1=COPc, Coefficient of Performance of Chiller, t= time/hr, Xi= chiller water inlet temperature and, Xo= chiller water outlet temperature

Table 1.0 presents an analysis of variance for the regression model of the Chiller's Coefficient of Performance, which examines the model's goodness-of-fit statistics.

Table 1 Analysis of Variance for regression model, COPc

Source	DF	SS	MS	F	P
Regression	3	51.171	17.057	79.51	0.000
Residual Error	6	1.287	0.215		
Total	9	52.458			

S = 0.463160 R-Sq = 97.5% R-Sq(adj) = 96.3%

Table 1.0 indicates that the regression equation for COPc is significant because the p-value is less than 0.05; it is deduced that the relationships between COPc, time, chiller water inlet and outlet temperatures are statistically significant because the p-values for these terms are less than the 0.05 at 95% confidence limit. The determination coefficient, R^2, is 97.5 percent. It denotes that the 97.5 percentage of variation in the answer that the model explains. The higher value of R^2, 97.5 percent, It indicates that the model matches the time, chiller water inlet, and outlet temperatures on COPc data more precisely. The adjusted R^2 value of 96.3 percent takes the number of predictors into account to aid in prediction accuracy.

The S-value of 0.463160 indicates how far the observed values deviate from the fitted values. The lower the value of S, the more closely the model predicts the response.

Energy Efficiency Ratio of Chiller, EERc

The Energy Efficiency Ratio Chiller characteristic model is shown in eqn, (9) as a function of time, chilled water inflow and outlet temperatures

The regression equation is Y2 = 55.3 - 0.603t - 23.7 Xi + 25.0 Xo(9)

Where, Y2 = EERc, Energy Efficiency Ratio of Chiller, t= time/ hr, Xi = chilled water inlet temperature, and Xo = chilled water outlet temperature. The analysis of variance in Table 2.0 analyses the model's goodness-of-fit statistics for the regression model of the Chiller's Energy Efficiency Ratio.

Table 2 Analysis of Variance for regression model EERc

Source		DF	SS	MS	F	P
Regression		3	595.02	198.34	79.51	0.000
Residual Error		6	14.97	2.49		
Total		9	609.98			

S = 1.57937 R-Sq = 97.5% R-Sq(adj) = 96.3%

The regression equation for EERc is statistically significant because the p-value is less than 0.05, as shown in Table 2; the relationships between EERc, time, chiller water inlet and outlet temperatures are statistically significant because the p-values for these terms are less than the 0.05 significance level. R^2 is a 97.5 percent determination coefficient. It denotes that the model explains 97.5 percent of the variation in the response. The model matches the time, chiller water inlet, and outlet temperatures on EERc data more correctly the higher the R^2 value, 97.5 percent. The adjusted R^2 score of 96.3 percent takes the number of predictors into account in order to aid in model selection. The S-value of 1.57937 represents the distance between the data and the fitted values.

Coefficient of Performance of cooling tower, COPct

A characteristic equation model of cooling tower Coefficient of Performance as a function of time, cooling tower water inlet and outlet temperatures is shown in eqn(10)

The regression equation is Y3 = 25.1- 0.444t - 9.76 Xi + 10.3 Xo (10)

Where, Y3 = COPct, Coefficient of Performance of Cooling Tower, t= time/ hr, Xi = cooling tower water inlet temperature, Xo = cooling tower water outlet temperature

Table 3.0 presents an analysis of variance for the regression model of the cooling tower water's Coefficient of Performance, which examines the model's goodness-of-fit statistics.

Table 3.0: Analysis of Variance for regression model for COPct

Source	DF	SS	MS	F	P
Regression	3	243.429	81.143	20.52	0.001
Residual Error	6	23.721	3.953		
Total	9	267.150			

S = 1.98833 R-Sq = 91.1% R-Sq(adj) = 86.7%

Table 3 reveals that the regression equation for COPct is significant since the p-value is less than 0.05; the correlations between COPct, time, cooling tower water inlet and outlet temperatures are statistically significant because the p-values for these terms are less than the 0.05 at 5% significance level. R^2 is 91.1 percent determinant. It means that the model accounts for 91.1 percent of the variation in the outcome. The greater the R^2 value, 91.1percent, the more exactly the model matches the time, chiller water inlet, and outlet temperatures as measured by COPct. The adjusted R^2 score of 86.7 percent takes into consideration the number of predictors, which improves prediction accuracy. The S-value of 1.98833 represents the distance between the observed and fitted values.

Energy Efficiency Ratio of Cooling Tower, EERct

The cooling tower characteristic model for the Energy Efficiency Ratio is illustrated in eqn, (11) as a function of time, cooling tower water intake, and output temperatures.

The regression equation isY4= 85.4-1.55t-33.3 Xi + 35.1 Xo (11)

Where Y4 = EERct, Energy Efficiency Ratio of Cooling Tower, Xi, = Cooling tower water inlet temperature, and Xo = Cooling tower water outlet temperature.

The goodness-of-fit statistics for the regression model of the cooling tower's Energy Efficiency Ratio are examined using the analysis of variance in Table 4.

Table 4 Analysis of Variance for regression model for EER ct

Source	DF	SS	MS	F	P
Regression	3	2830.62	943.54	20.52	0.001
Residual Error	6	275.83	45.97		
Total	9	3106.45			

S = 6.78021   R-Sq = 91.1%   R-Sq(adj) = 86.7%

Table 4.0 shows that the regression equation for EER ct is statistically significant because the p-value is less than 0.05; the relationships between EER ct, time, and chiller water inlet and outlet temperatures are statistically significant because the p-values for these terms are less than the 0.05 at 95 % confidence limit. The R^2 coefficient of determination is 91.1 percent. It means the model accounts for 91.1 percent of the variance in the response. The higher the R^2 score, 91.1 percent, the better the model fits the time, chiller water inlet, and outlet temperatures on EER ct data. The adjusted R2 score of 86.7 percent takes into consideration the number of predictors in order to aid in model selection. The difference between the data and the fitted values is represented by the S-value of 6.78021.

CONCLUSION

The following are the findings of this study: the operation of a central water chiller air conditioning system model LSBLG 1200/MF was evaluated and characteristics parameters were measured. The performance curves were produced; COP and EER models were established. The chiller and cooling tower have maximum performance coefficients of 52 percent and 20 percent, respectively. The chiller and cooling tower, have maximum EERs of 177 and 68 respectively. Multiple regressions were used to generate model equations for the statistical relationship between operational parameters such as input and output temperatures as a function of local time, as well as response variables such as COP and EER. The performance of the system can be evaluated using established models. Constructed characteristic models for the coefficient of performance and energy efficiency ratio can be used, to forecast the performance of a central water chiller and air conditioning system.

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