Current Journal of Applied Science and Technology

32(3): 1-13, 2019; Article no.CJAST.46188
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Modelling the Condensed Water Discharge Rate in an Air Conditional System in South West, Nigeria

O. S. Bamisaye[1*] and P. K. Oke[1]

[1]Department of Production and Industrial Engineering, Federal University of Technology, Akure, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2019/46188
Editor(s):
(1) Dr. Ahmed Fawzy Yousef, Associate Professor, Department of Geology, Desert Research Center, Egypt.
Reviewers:
(1) Oludele Adebayo Adeyefa, University of Ibadan, Nigeria.
(2) Halil Görgün, Dicle University, Turkey.
(3) Nasser Mosafa Abd Elrahman Elashmawy, King Saud University, Saudi Arabia.
Complete Peer review History: http://www.sdiarticle3.com/review-history/46188

Original Research Article

Received 23 September 2018
Accepted 01 January 2019
Published 18 January 2019

ABSTRACT

Aims: This work is aimed at developing an empirical model for predicting condensed water discharge rate in an air conditional system, most especially in Nigerian offices.
Study Design: Quantitative study. Relevant data on condensate discharge rate was collected.
Place and Duration of Study: An office located within the School of Engineering and Engineering Technology Building of the Federal University of Technology, Akure, Ondo State, Nigeria, between November 2015 to April 2016.
Methodology: The method used consists of data collection and readings such as condensate volume, dry bulb temperature, relative humidity, sensible heat ratio, and dew point temperatures. A split type air-conditioning unit with a cooling capacity of 2500 W, using refrigerant and rated air flow rate of 400 m^3/hr was used to determine the amount of condensate rate.
Results: The result of six-month data collected showed that a total of 528 L of condensed water was collected at the split type air conditional unit. The highest condensate discharge rate of 1.07 L/hr was recorded on 6th and 7th April 2016. The coefficient of determination, R^2, obtained for first, second and third order multiple linear regression model were 0.964, 0.9793, and 0.9803 respectively. The developed multiple linear regression model was used to compare the experimental

**Corresponding author: E-mail: bamisayesylvester1988@gmail.com;*

and predicted values of the condensate from the air conditional unit used for the study.
Conclusion: The developed model offers ease of prediction and forecasting of the amount of condensate discharge rate. This study confirms that relative humidity, sensible heat ratio, dry bulb temperature, and dew point temperature are the most significant factors contributing to an increase in condensate discharge rate.

Keywords: Air condition; regression model; reclaimed water; forecasting; modern building.

1. INTRODUCTION

The significance of using reclaimed water in air conditioning systems is a frequent feature of certain urban infrastructure in some part of the world. The reclaimed water is referred to as condensed water. Condensate is referred to the water that settles on a cool surface because the temperature of the surface is beneath the point at which moisture in the air forms water droplets. The volume of the space, the number of persons and their activity determines the amount of outdoor air required and the amount of moisture in it. Condensed water is a built-in by-product of building heating, ventilation, and air conditioning (HVAC) systems formed from moisture in the air. It is high-grade water therefore, it can be collected and utilized on-site with limited treatment. More specifically, condensed water comes up in the evaporator area of the air-conditional unit where evaporative cooling drives the heat exchanger [1]. The air dehumidification on finned evaporator coils was solved, using an approach that describes the surface efficiency to the enthalpy transformation of cooled moist air [2]. According to Geshwiler [3], the occupancy action impact the fresh air ratio and the ratio may differ from 100% fresh air in applications like a laundry room, and electrical room. The utilization of high amounts of outside air, cooling load profile and 24 hours daily operation, the cooling coils in the laboratory facilities can furnish a significant source of condensate water [4]. The climate in Akure, Ondo State Nigeria is impacted mainly by the rain-bearing southwest monsoon winds from the ocean and the dry northwest winds from the Sahara Desert. Maximum daytime temperatures rarely exceed 34 °C and low as 22 °C, a mean annual relative humidity of about 80% also characterize the climate [5]. Owing to the weather condition in Akure, modelling the rate of discharge of condensed water in an air conditional system is a good potential opportunity that needs to be studied. All buildings in the Federal University of Technology, Akure are air-conditioned with a variety of different equipment being used. In the School of Engineering and Engineering Technology Building, mini-split units and window units are used. In any air conditioning system operating with high outside dew point temperatures, there will be a formation of condensed water generated in the fan coils that must be disposed or diverted out of the building. The formed condensed water from air conditioning units is an often overlooked source of freshwater. The consequent build-up can provide a large amount of freshwater that can be used to balance the use of potable water. In most buildings, this condensate is often sent to an open ground which can be a route to condensate discharge piping to the nearest sanitary drain. The evaluation of condensate by-product for big structures during hot season differs between 0.1 to 0.3 L/kW for every hour the cooling system worked. It was mentioned that for those designing buildings in hot and humid climates, maximum condensate output during summer months could be almost between 6 to 7 ml/s/1000 m² of the cooled area [6]. The measure of condensate water basically dependent on local climate, heating, ventilation and air-conditioning design, the operation of the building, dry bulb temperature, relative humidity, sensible heat ratio, and dew point etc. A report by AWE [7] shows that the amount of condensed water can range from 11 to 38 Litres/day per 92.9 m² of air-conditioned space. Another study by Shahid [8], provided an estimate for typical condensate production in large buildings during summer months in San Antonio as 0.378 to 1.135 L/h of water per ton of cooling. San Antonio Condensate Code [9] described that big volume of low-temperature condensate water can be collected during the dehumidification process in the air conditioning systems and employed in the commercial buildings having a big cooling capacity plant. Painter [10] developed a predictive modelling technique for a dedicated outdoor air handling unit with enthalpy wheel energy recovery and also condensate production in three locations in Texas; San Antonio, Houston, and Dallas/Fort Worth. Lawrence et al. [11] highlighted that a forecasting model could be used to appraise the condensed water harvested for a retrofit. Investigating sustainability issues associated with the collection, storage, and modelling of condensate water from selected air conditioning equipment for an institutional building sited on the Education City Campus in Doha, Qatar was enhanced by Bryant and Ahmed [12]. The usefulness of using condensate as an added source of water and also the impact of climate condition and space occupancy on the volume of condensate generated were investigated by Lawrence et al. [13].

International building codes, ordinances, and standard that accompany the design and pursuance of water-conserving practices, with the idea of assessing condensate collection and safeguarding human health and safety is described by International Code Council [14]. According to American Society of Heating [15], air conditioner condensate can be categorized under the description of alternative on-site sources of water and the word "reclaimed water" is only applicable in the impression of municipal reclaimed water. The temperature, humidity and condensates data collected in various locations mentioned in the available literature cannot be used directly in Nigeria because of environmental conditions. A split type air-conditioning unit with a cooling capacity of 2500 W, using refrigerant and rated air flow rate of 400 m^3/hr was used to determine the amount of condensate rate. An empirical model was developed to compare the experimental and predicted values of the condensate from the air conditional unit used for the study.

The objective of this study is to collect the weather data and condensate from the air-conditioning unit, develop an empirical model to determine the rate of condensate and finally validate the empirical model for the purpose of forecasting the amount of condensate at specific environmental conditions in Southwest, Nigeria.

2. MATERIAL AND METHODS

2.1 Materials

The equipment used is an existing split type air-conditional unit with a cooling capacity of 2500 W, with refrigerant R-22. Graduated measuring cylinder (500 ml), indoor/outdoor thermo-hygrometer (temperature measuring range: -10 °C to 70 °C, humidity measuring range: 20% to 90% and outside sensor with 3 meters cable). These were bought at Pascal Delson Scientific Limited, Akure. While the collector (25 litres) and drain pipe (using 25 mm PVC adaptor) were purchased in King's Local market, Ondo State.

2.2 Selection of Environment

The facility chosen for this study was the School of Engineering and Engineering Technology Building which is a two storey, concrete construction building consisting of five classrooms, ten laboratories, and eighty-three offices. It is a typical campus facility with heavy use during the day with activity closing by 4 pm in the evening. The air conditioning and ventilation for this building is supplied through eighty-three separate air conditioning units (window and split type) which are all wall mounted. Condensate removal system for this building showed that condensate discharge at each unit was routed via external piping from the air-conditioning unit to open ground. An office located on the ground floor of the facility was selected for this study. The office selected can accommodate at least four people; the volume of the office selected was 33.8 m^3.

2.3 Experimental Procedure

The performance of the indoor and outdoor unit of the split air-conditioning system was tested if it is working according to design capacity and the nominal cooling rating. After the split indoor and outdoor air-conditioning unit had been completely tested, 25 litres container (as a collector) was connected to the drain pipe which is sized assuming a gravity-driven flow. Drain pipe must be greater than or equal to 19 mm internal diameter and must not decrease in size. The drain line was sized in accordance with the required standard. Care was taken to ensure continuous horizontal slope along the discharge path by proper installation of pipe joints to avoid collection of condensates along the discharge path. The drain pipe was then connected to 25 mm PVC adaptor and positioned under the outdoor unit. The condensate collection apparatus was incorporated with minimum impact on the existing facility and the opening at the drain level was capped so that the pipe would fill with condensate water from the split air-conditioning system installed for examination. As soon as the condensate level reached the new drain pipe, it was directed to the 25 litres container. The indoor and outdoor temperature, as well as its relative humidity, were measured using thermo-hygrometer. The relative humidity measurement accuracy of the device was ±3.5% from 20% to 90% and a resolution of 0.1%. The temperature measurement range of the device was -10 °C to +70 °C, resolution 0.1°. As the collector was filled to a given level, for a period of an hour, the condensate reading was collected using a measuring cylinder (500 ml) in relation to the changes in the weather parameters. This procedure was repeated on an hourly basis for a period of 8hrs per day from Monday to Friday.

2.4 Data Collection and Analysis

The data collected from the research were analysed using a psychrometric chart and Microsoft Excel to calculate the condensate production rate given hourly weather conditions from November 2015 to April 2016. The analysis helps to determine the amount of condensed water that can be collected in six months period from the split air conditioning unit with a cooling capacity of 2500 W. The weekly average indoor condition was 23 °C and 55% relative humidity, which fall within the comfort zone air condition. Although the weekly average indoor condition changes for the month of December 2015 through February 2016 to 22 °C and 41% relative humidity. The dew point temperature range varies from 13 °C to 25 °C. The surface temperature of the coil was between the range of 10 °C - 12 °C, the room sensible heat factor for the office space varies from 0.55-0.85. The mass rate of condensed water is calculated from the relative humidity change between the inlet and exit states. Since the mass of the condensed water determined is from the air conditional, the mass flow of dry air was determined using the relationship in equations (1) and (2).

$$\dot{m}_w = \dot{m}_d(W_3 - W_4) \quad (1)$$

$$\dot{m}_d = \frac{\dot{m}_w}{(W_3 - W_4)} \quad (2)$$

where, $\dot{m}_w$ is mass flow of condensed water, per unit time (kg/hr.,); $\dot{m}_d$ is mass flow of dehumidified air, per unit time (kg/hr., kg/min, kg/s); and (W_3 - W_4) is the differences between the moisture contents at mixed conditions (inlet of the coil) and the air supplied to the cooling coil, kg/kg$_{(air)}$.

The total sensible and latent heat handled by the refrigerating equipment of the air-conditioning system is determined using equations (3) and (4) respectively.

$$Q_{TSH} = C_{pm}\dot{m}_d(t_{d3} - t_{d4}) \quad (3)$$

where, Q_{TSH} is Total sensible heat (kJ); $\dot{m}_d$ is the Mass flow of dehumidified air, per unit time (kg/hr.,); $(t_{d3} - t_{d4})$ is Differences between the air been cooled at different temperatures at the evaporator, K and C_{pm} , Humid specific heat (kJ/kgk).

$$Q_{TLH} = \dot{m}_d h_{fg}(W_3 - W_4) \quad (4)$$

where, Q_{TLH} is Total latent heat (kJ); $\dot{m}_d$ is the Mass flow of dehumidified air, per unit time (kg/hr.,); $(W_3 - W_4)$ is differences between the moisture contents at mixed conditions (inlet of the coil) and the air supplied to the cooling coil, kg/kg $_{(air)}$; and h_{fg} is the Latent heat of vapourization (kJ/kg).

2.5 Formulation of the Model

The formulation of the model to predict the condensate discharge rate begins with the identification of the contributory factors that either enhance or inhibit the formation of condensate in air conditioning system used to regulate the thermal comfort of a particular space. Some of the factors identified and used in the formulation of the model include sensible heat ratio (SHR), outside temperature (T), dew point (DP), relative humidity (RH), and volume of air-conditioned space (V_{space}). Hence, the rate of condensate discharge is a function of all these identified factors which is mathematically expressed in equation (5) as:

Rate of condensate discharge, CDR = f (SHR, T, DP, RH, V_{space}) (5)

The simplest form of an empirical model that can be developed from the factors to make a numerical prediction of the condensate discharge rate is a first order multiple regression model otherwise called multiple linear regression model. This model is generally expressed as equation (6).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \quad (6)$$

where; y represents the rate of condensate discharge (l/hr), (β_0, β_1, β_2, β_3, β_4) are the regression coefficients and (x_1, x_2, x_3, x_4) represent relative humidity (%), outdoor temperature (°C), sensible heat ratio and dew point (°C) respectively, which are the factors considered in this study. It is noteworthy that the volume of space air-conditioned remains constant throughout the experimental period. In equation (6), there are five (5) regression coefficients to be determined, hence five (5) set of equations, to be solved simultaneously to determine the coefficients, needs to be developed. Based on the data obtained from the experiment, the set of equations can be obtained from the following mathematical expression as equation (7).

$$\beta_0 \sum_{i=1}^{n}(x_4) + \beta_1 \sum_{i=1}^{n}(x_1 x_4) + \beta_2 \sum_{i=1}^{n}(x_2 x_4) + \beta_3 \sum_{i=1}^{n}(x_3 x_4) + \beta_4 \sum_{i=1}^{n}(x_4{}^2) = \sum_{i=1}^{n}(x_4 y) \quad (7)$$

Where; n is the number of observations made over the period of experiment i.e. November 2015 – April 2016. The values of the factors considered were collected and the condensate discharge rate for each day was obtained by dividing the total volume of condensate collected daily by the duration over which it was collected, i.e. eight (8) hours. The adequacy of this model is accessed by examining the value of the coefficient of determination, R^2, which indicate the variability in the data employed. Thus, formulating the set of equations as shown in equation (7), and solving simultaneously, the values of the coefficients were obtained for the first order multiple regression model. These values are:

β_0 = -2.087 , β_1 = 0.0033, β_2 = 0.02074, β_3 = 2.230, and β_4 = 0.01145

Therefore, the fitted first order regression equation for the condensate discharge rate is given in equation (8):

$$y = -2.087 + 0.0033x_1 + 0.02074x_2 + 2.23x_3 + 0.01145x_4 \quad (8)$$

The coefficient of determination, R^2, obtained for this model is 0.964. This makes the model to be considered as a good fit to predict the rate of condensate discharge. However, the model with a better fit can be obtained by considering the formulation of a second order multiple regression equation.

The fitted second order regression equation obtained from the experimental observations made over the period of November 2015 – April 2016 is given as equation (9):

$$y = 6.45 + 0.476x_1 - 0.328x_2 - 7.04x_3 - 0.127x_4 - 0.000152x_1^2 + 0.00454x_2^2 - 0.06x_3^2 - 0.00012x_4^2 - 0.0018x_1x_2 + 0.00355x_1x_3 - 0.00004x_1x_4 + 0.16x_2x_3 + 0.00299x_2x_4 + 0.145x_3x_4 \quad (9)$$

The coefficient of determination, R^2, of the second order multiple regression model is 0.9793, which is greater than the value of the first order multiple regression model. Thus, the second order model is considered a better fit with higher prediction adequacy. It can be deduced that as the degree of model equation increases, the greater the accuracy and adequacy of the model would be. The third order regression equation was obtained which consists of the cubic terms, quadratic terms and all the possible interaction terms for the factors considered.

The fitted third order regression equation obtained is given as equation (10):

$$y = 4.8 + 0.0227x_1 - 0.87x_2 + 23.3x_3 - 0.125x_4 + 0.001024x_1^2 + 0.025x_2^2 - 44.3x_3^2 - 0.0044x_4^2 - 0.00211x_1x_2 + 0.0144x_1x_3 - 0.00051x_1x_4 + 0.148x_2x_3 + 0.00491x_2x_4 + 0.163x_3x_4 - 0.00007x_1^3 - 0.00026x_2^3 + 21.7x_3^3 + 0.000065x_4^3 \quad (10)$$

The coefficient of determination, R^2, of the third order multiple regression model is 0.9803, which is greater than the value of that of the second order multiple regression model. The correlation coefficient, R, is obtained as 0.9916, which made the third order model to be considered as the best model to predict condensate discharge rate.

3. RESULTS AND DISCUSSION

3.1 Total Condensate Volume

The results presented here spanned a period of six months (November 2015 through April 2016) and the condensate water data collected is from Monday to Friday within the working hours, that is, from 8 am to 4 pm. The result showed that over the six month period, a total of 528 Litres of condensed water was collected from split air conditional unit of the office used for the study. This figure indicates the amount of reclaimed water source that is not in use. Higher condensed water volumes were collected during the months of November, March, and April. Comparatively, lower condensate water volumes were collected during the months of December, January, and February. As the average relative humidity increased, there was a corresponding increase in the amount of condensate collected. The total volume of condensate water produced per month in the office selected for the study is shown in Fig. 1.

3.2 The Relative Humidity and Outside Dry Bulb Temperature against the Number of Days

The value of the temperature can be described as dry bulb temperature of the air which maintains the mean value of 30ºC over the period of the days inspected. According to Fig. 2, the minimum temperature recorded was 25ºC on day 129 (28^{th} – 04 – 2016) while the maximum temperature of 31ºC was recorded on days 17^{th} to 19^{th} respectively (24^{th} to 26^{th} – 11 – 2016). From Fig. 2, it can be inferred that the temperatures of the air vary over the range of 6ºC between days 1 to day 130, over the period of data inspections. The result of the relative humidity, RH, for the numbers of days considered showed a wide range of variations with the average value of 55% between the period considered. The lowest RH obtained was 22% on day 34 (17/12/2015) and a maximum value of RH was 72% which was recorded on days 102 and 104 respectively (22^{nd} and 24^{th} /03/2016). The low value of RH is an indication of the high amount mass of saturated air over this period and low amount mass of water vapour present in unit mass of air at this period, while the high amount of RH would have resulted from the low amount of mass of saturated air and the amount of mass of water vapour present in a unit amount of air. Fig. 2. shows the plot of the relative humidity and outside dry bulb temperature against the number of different days the experiment was carried out respectively.

3.3 Mass of the Dehumidified Air with the Total Latent Heat and Total Sensible Heat

The weekly result of the mass of dehumidified air, total latent heat and total sensible heat handled by the refrigerating equipment of the air-conditioning system is shown in Fig. 3. During the dehumidification process, the sensible heat transfers by convection from the air to the surface, and the latent heat transfer occurs because of the condensation on the surface. It was observed that the sensible heat adds more heat to the moist air in order to increase its temperature to form moisture on the coil than the latent heat. At a point in Fig. 3, the latent heat appreciates over the sensible heat and later decreases. The sensible and latent heat was high during the cooling season and low during harmattan because of low moisture found in conditioned space, moisture from human respiration, perspiration, and evaporation of moisture from clothing.

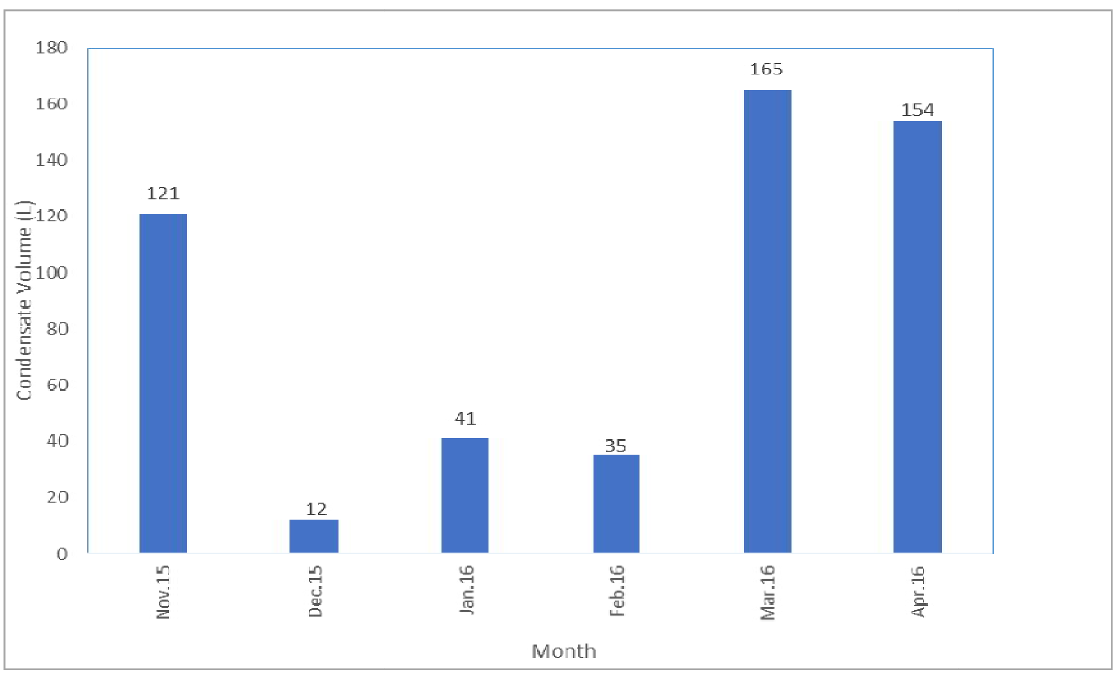

Fig. 1. Condensate volume from November 2015 through April 2016

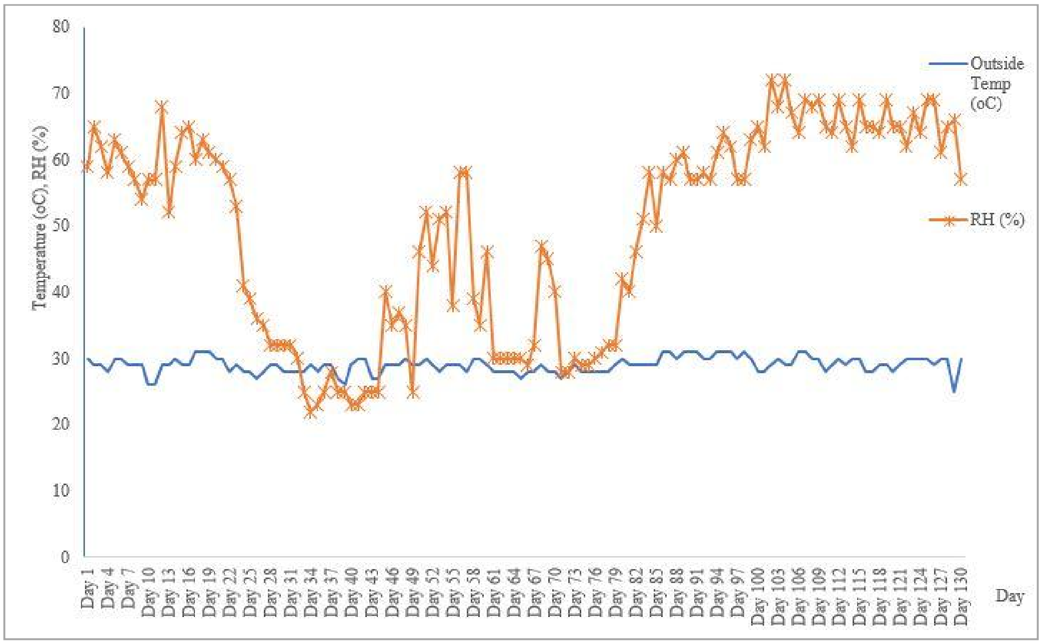

Fig. 2. The plot of relative humidity and outside dry bulb temperature against the number of days

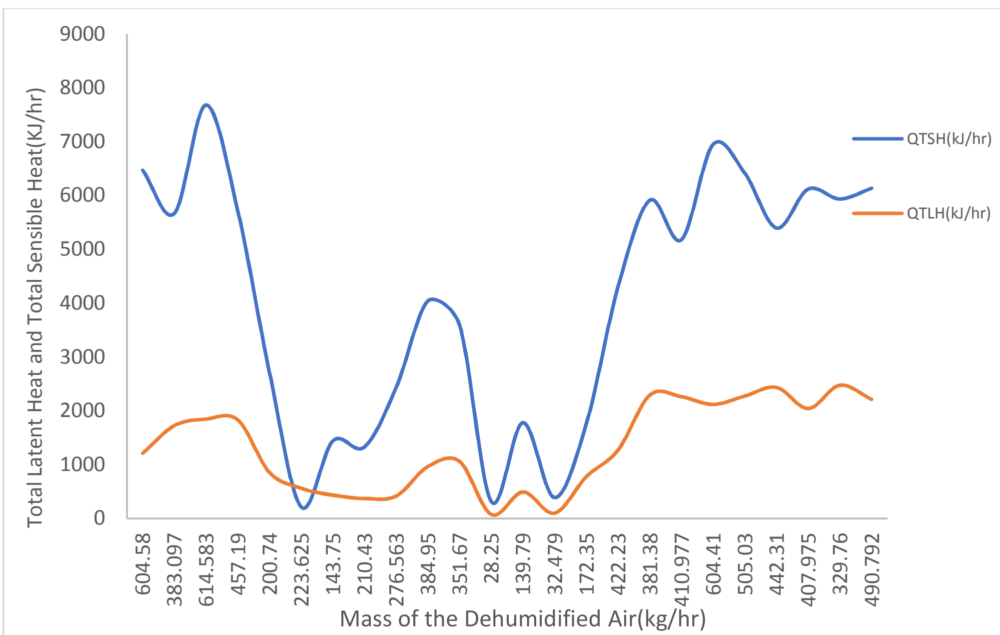

Fig. 3. The total latent heat and total sensible heat against a mass of the dehumidified air

3.4 Results of the Model Developed

In order to establish the reliability of the models as being capable of predicting the condensate discharge rate, the rate values obtained from the model based on the prevailing factor values, are compared to true experimental data to determine their percentage disparity. Fig. 4a - 4c shows the plot of the experimental values of the condensate discharge rate and the predicted values from the first order, second order and third order models respectively. As seen in Fig. 4b., the second order model predicted values almost relatively match with the experimental values of the condensate discharge. However, the model is limited to being able to give reliable prediction when there is drastic fluctuation in the condensate discharge and when the condensate discharge was near zero or zero as observed between 25 – 45 days of data collection. This was also observed in the behaviour of the first order model in Fig. 4a.

The third order model in Fig. 4c seems to be best appropriate as it can predict the intensification of the water, where there are zero values when compared with the experimental values of the condensate discharge. The correlation of determination for the third order model is higher than that of the first and second order, the third order model is considered in this work as the best option to predict the rate of condensate discharge from air conditioning systems.

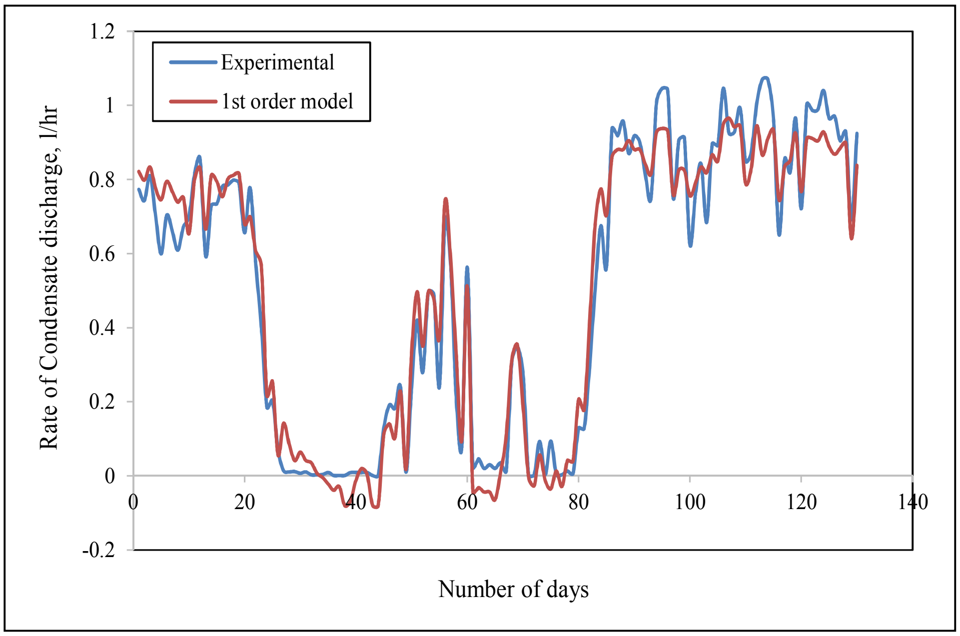

Fig. 4a. Comparison between experimental and 1st order model value of condensate rate

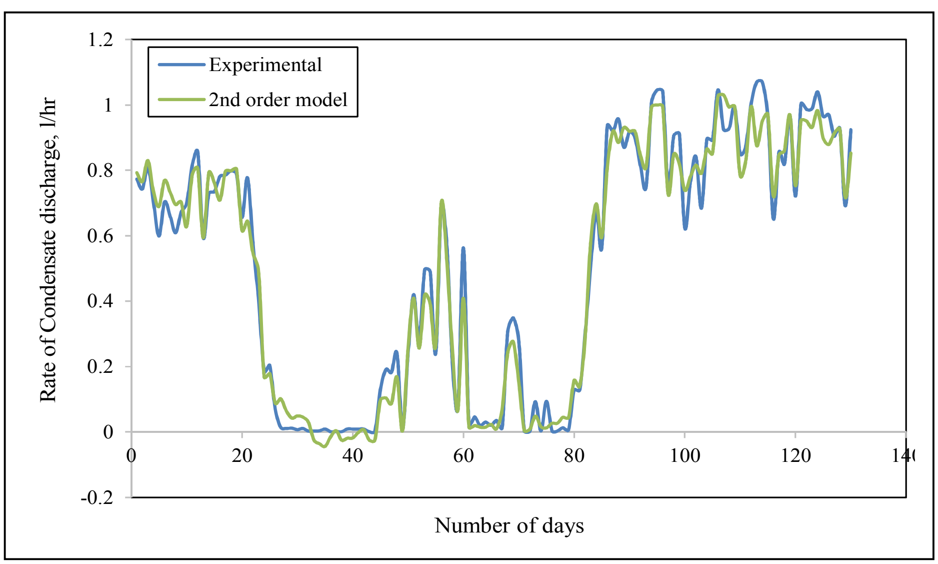

Fig. 4b. Comparison between experimental and 2nd order model value of condensate rate

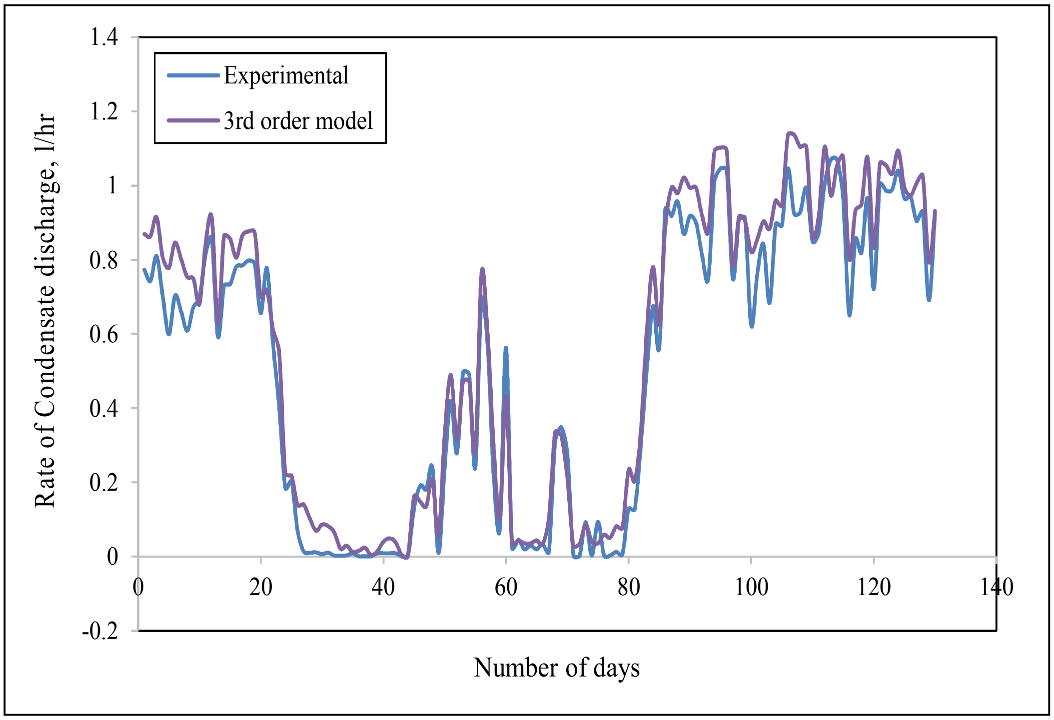

Fig. 4c. Comparison between experimental and 3rd order model value of condensate rate

3.5 Model Validation

The data obtained during the month of 19th - 23rd September 2016 was used to validate the accuracy of the model developed under this study. It was intended to examine if the model can reproduce the similar results for the weather conditions in the year 2016. Some of the data identified include sensible heat ratio (SHR), outside temperature (T), dew point (DP) and relative humidity (RH). For the validation of the model, the averages of data obtained from the experiment were fitted into the regression equations of 1st, 2nd, and 3rd order. The results of the regression model were compared to the experimented values in other to test for their correlations. The values of (x_1, x_2, x_3, x_4) represent relative humidity (%), outdoor temperature (ºC), sensible heat ratio, and dew point (ºC) respectively, which are the factors considered in this study. The experimental and predicted values of the condensate rate are shown in Table 1.

Fig. 5a - 5c shows the plot of the experimental values of the condensate discharge rate and the predicted values from the first order, second order and third order models respectively. The graphical presentation of the model predictions indicated that the third order model in Fig. 5c seems to be best appropriate as its predicted values relatively close to the experimental values of the condensate discharge. The first order model did not give a good match with the experimental values obtained, but rather under-predict the values and the second order model shows a little improvement but not too close to the experimental values. The correlation of determination for the third order model is higher than that of the second order, the third order model is considered in this month of September as the best option to predict the rate of condensate discharge from air conditioning systems. In September, the rainy season was still on, hence the relative humidity, RH, was high, ranging from (65 – 85) %, the outdoor temperature ranges from (24 – 30)°C, the Sensible Heat Ratio, SHR, was also high (0.83 – 0.85) and the dew point, DP, was high ranging from (20 – 23)°C. During this period, the condensate discharge rate, CDR, was high, ranging from (0.9 – 1.27) L/hr.

Table 1. The data obtained for September 19th - 23rd

DATE	X_1 (%)	X_2 (°C)	X_3	X_4 (°C)	Experimental	1st order model	2nd order model	3rd order model
19/09/2016	77	27	0.84	22	1.270	0.85218	0.90756	0.99518
20/**09**/2016	76	27	0.83	22	1.213	0.82658	0.87219	0.96095
21/**09**/2016	75	27	0.83	23	1.095	0.83473	0.88464	0.96492
22/**09**/2016	78	27	0.83	23	1.113	0.84463	0.89751	0.96405
23/09/2016	78	26	0.83	22	1.180	0.81244	0.90975	0.98678

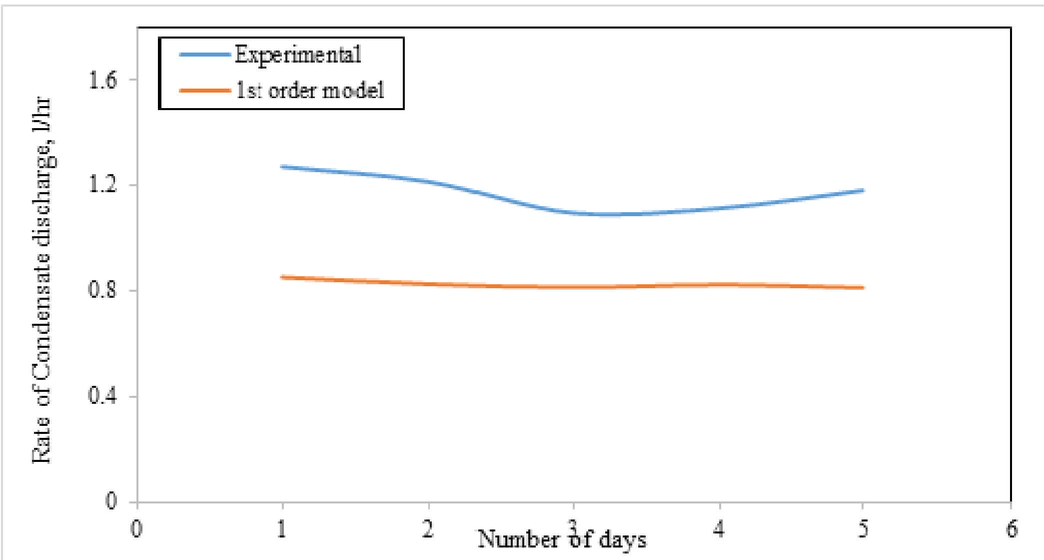

Fig. 5a. The plot between experimental and 1st order model value of condensate rate

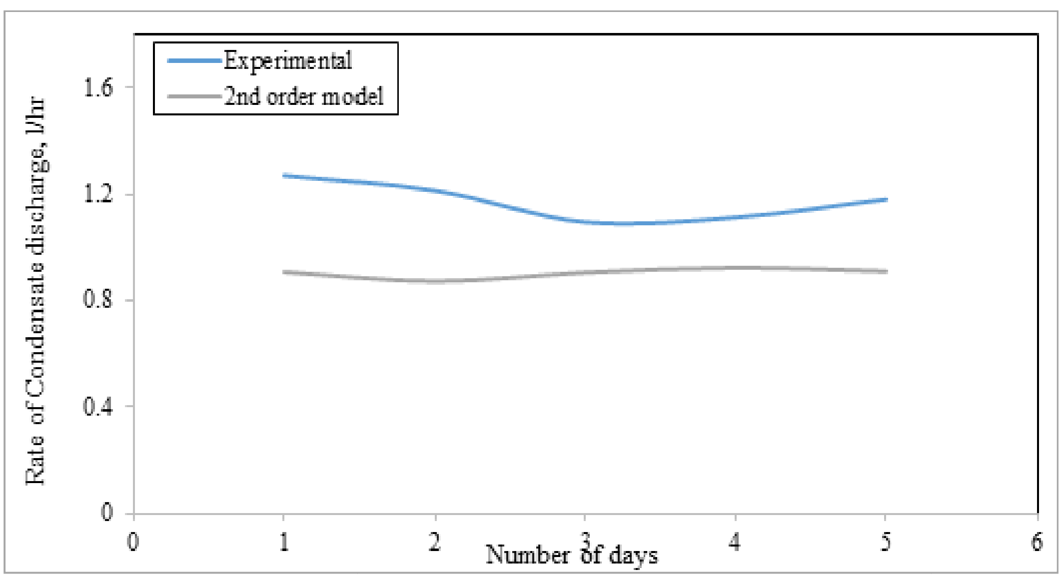

Fig. 5b. The plot between experimental and 2nd order model value of condensate rate

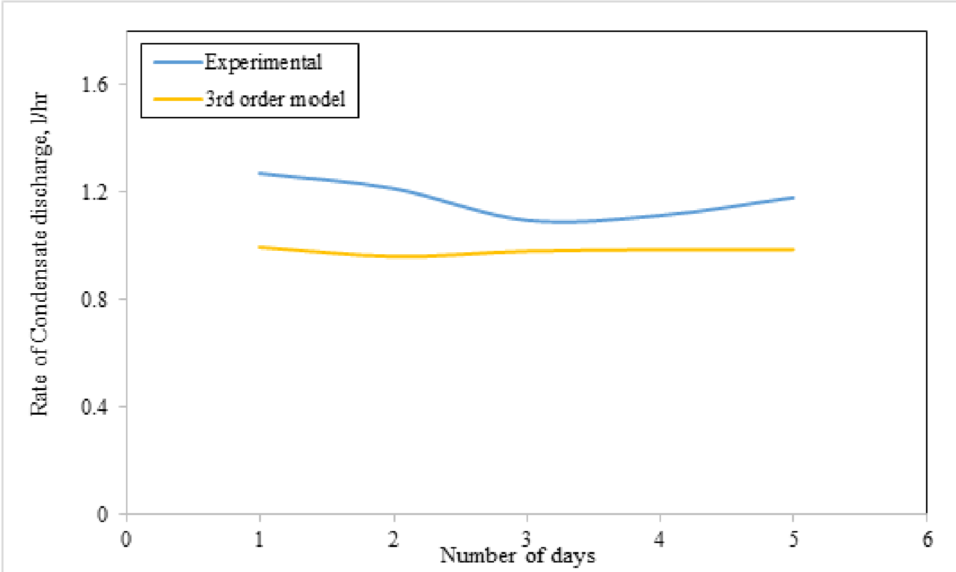

Fig. 5c. The plot between experimental and 3rd order model value of condensate rate

3.6 Discussion

The regression analysis of data collected during the month of the study showed significant improvement in the accuracy of the model in predicting the condensate production. The study is in line with [10] and [11] that use of a prediction model technique could be used to estimate the condensed water collected for an air handling unit. The adequacy of this model is accessed by examining the value of the coefficient of determination, R^2, which indicate the variability in the data employed. The coefficient of determination, R^2, of the first, second and third order are 0.964, 0.9793, 0.9803 respectively. The characteristics of the condensate discharge rate over the period of 130 days, from November 2015 – April 2016, is a true reflection of the seasonal variation in Southwest, Nigeria. In November, the rainy season was almost rounding off, hence the relative humidity, RH, was high, ranging from (52 – 68) % between the 1st day (2nd November) – 21st day (30th November). The outdoor temperature ranges from (26 – 31)ºC, the Sensible Heat Ratio, SHR, was also high (0.76 – 0.85) and the dew point, DP, was high ranging from (20 – 23)ºC. In this period, the condensate discharge rate, CDR, was high, ranging from (0.6 – 1) l/hr. However, this value decreases rapidly to near zero l/hr in December. In December, Harmattan, dry season sets in and RH drops to (22 – 36) %, SHR decreases to (0.55 – 0.59) and DP decreases also to (12 – 17)ºC. The near zero CDR persisted from 1st Dec. 2015 (22nd day) – 4th Jan. 2016 (46th day).

In January, the dryness persisted, however CDR began to increase from near zero as at the 46th day to 0.689 l/hr on 18th Jan. (56th day) with RH (35 – 58) %, outdoor temperature (28 – 30)ºC, SHR (0.55 – 0.8) and DP (17 – 22)ºC; and thereafter nosedived to near zero CDR towards the end of the month at the 61st day (25th January). In February, there have been signs that the rainy season is approaching, though the dryness persisted until 18th February (79th day) with RH (28 – 32) %, SHR (0.55 – 0.8), DP (12 – 13)ºC, however there was exception to 68 – 70th days (3rd – 5th Feb.), the CDR slightly increase to (0.28 – 0.35) l/hr with improved RH (40 – 47)%, SHR (0.56 - 0.67) and DP (17 – 19)ºC.

After the 79th day, as the month of March is approaching, there was a rapid increase in the CDR. Since the months of March and April were rainy season period, the RH, SHR and DP have increased to between (57-72) %, (0.79 – 0.85) and (22 – 25) ºC respectively with outdoor temperature ranging from (25 – 31)ºC. Thus, making the CDR recorded between 86th day (27th Feb.) – 130th day (29th April) to be in the range of (0.623 – 1.07) l/hr. Over the period of experimental observation in this study, the highest condensate discharge rate of 1.07 l/hr is recorded on the 113th day (6th April) and 114th day (7th April) of 2016. In general, the most significant factors contributing to an increase in the rate of condensate discharge is increase in the RH, SHR, and DP. The study agrees with the findings of [4] and [6], they confirm that amount of condensate water largely dependent on local climate, heating, ventilation and air-conditioning design, dry bulb temperature, relative humidity, and sensible heat ratio.

4. CONCLUSION

The study was carried out to develop an empirical model for predicting condensed water discharge rate in an air conditional system in other to ascertain the volume of useful water that is wasted, most especially in Nigerian offices. The analysis showed that over the six month period of the 8 hours daily operation of the air conditioning unit, a total of 528 L of condensed water was collected from the 2500 W split air conditioning unit of the office space (33.8 m^3) used for the study. The analysis of the data collected suggested a multiplying factor for determining the amount of condensate production possible from such systems in order to effectively use it for different purposes such as toilet flushing and as a distilled water for laboratory uses. The regression model of the first, second and third order was developed based on data collected from the period of November 2015 - April 2016. It can be deduced that as the degree of the model equation increases, the greater the accuracy and adequacy of the model. The results of correlation analysis for the model equations showed that dew point temperature, sensible heat ratio, relative humidity have a strong correlation with the hourly condensate production rate. This study shows that condensate from air conditioning unit has a potential for water sustainability that should be tapped instead of leaving it to simply drained off into the open grounds as waste and consequently disfiguring and destroying the surface of the structure.

5. RECOMMENDATIONS

In promoting reclaimed water source and water sustainability in Nigeria, it is thereby recommended that further research needs to be conducted on condensed water discharge rate for two consecutive years to give a perfect scenario for water sustainability. Further studies should also be done in other to detect more factors that can determine condensate discharge rate from an air-conditioning unit. The further studies can help to reduce the cost being spent per month on water supply.

ACKNOWLEDGEMENTS

Authors hereby acknowledge the technical contributions of Engr. A.Y. Oyerinde of the department of Production and Industrial Engineering of Federal University of Technology Akure, Nigeria; during the course of this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Diana DG. San Antonio collection and use of manual for commercial buildings. San Antonio City Code Manual. 2013;1:9-12.
2. Habeebullah BA. Potential use of evaporator coils for water extraction in hot and humid areas. Elsevier Limited. 2009;237:330–345.
3. Geshwiler M. American Society of Heating, Refrigerating, and Air-Conditioning Engineers Pocket Guide. Guide for Air Conditioning, Heating and Ventilation. Second Edition, Atlanta, United States; 2005.
   ISBN-10:1-931862-78-8
4. Johnson GR. Heating, ventilating and air-conditioning design for sustainable laboratory facility. Journal of American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2008;24-34.
5. NIMET. Nigeria daily weather forecast; 2015.
   Available:www.nimet.gov.ng/weather/akure/Nigeria
   Accessed on 20 March 2015.
6. Guz K. Condensate water recovery. Journal of American Society of Heating, Refrigerating, and Air-Conditioning Engineers. 2005;47:54–56.
7. AWE. Alliance for water efficiency. Accessed on 15 February 2016.
   Available:www.allianceforwaterefficiency.org/CondensateWaterIntroduction.aspx
8. Shahid AK. Conservation of potable water using chilled water condensate from air conditioning machines in hot & humid climate. International Journal of Engineering and Innovative Technology. 2013;2277-3754.
9. San Antonio condensate code. A water conservation and reuse code. Guide for the San Antonio Condensate collection for commercial buildings. 2013;10:01-0984.

10. Painter F. Condensate harvesting from large dedicated outside air-handling units with heat recovery. Journal of American Society of Heating, Refrigera-ting, and Air-Conditioning Engineers. 2009;115:573–580.
11. Lawrence T, Perry J, Dempsey P. Capturing condensate by retrofitting AHUs. Journal of the American Society of Heating, Refrigerating and Air Conditioning Engineers. 2010;52:48–54.
12. Bryant JA, Ahmed T. Condensate water collection for an institutional building in Doha, Qatar. Paper presented at the sixteenth symposium on improving building systems in hot and humid climates, Dallas, Texas. 2008;15-17.
13. Lawrence T, Perry J, Dempsey P. Capturing condensate by retrofitting AHUs. Journal of the American Society of Heating, Refrigerating and Air Conditioning Engineers. 2010;52:48–54.
14. International Code Council. International green construction code. Guide for the construction of sustainable buildings for green initiatives. 2012;1:700-2012.
15. American Society of Heating, Refrigera-ting, and Air-Conditioning Engineers. The standard for the design of high perfor-mance green buildings. 2014;189:1.

© 2019 Bamisaye and Oke; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/46188