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Condensate testing, recovery, quantity analysis and forecasting in Guwahati city

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Abstract: In hot humid climates, such as the Guwahati, the air-cooling process of air conditioner can result in considerable amounts of water. In this paper quality and quantity analysis of condensate of air conditioner at the environmental condition of Guwahati city is done. Further estimation and forecasting the amount of condensate generation in Guwahati city is done for the next five years based on the sales of 1.5-ton split air conditioner. It is observed that only a single 1.5-ton AC can generate an average amount of 1.68 litters/hour of condensate in a typical day of August in the climatic condition of Guwahati. Further in this paper one attempt is made to find out the condensate generate potential of a 1.5-ton split air conditioner when the evaporator coil is integrated with a mixed air ventilation system (MAVS). It is observed that with MAVS the same1.5-ton split air conditioner can generate condensate of amount 2.30 Liters/hr.

Keywords: split air conditioner, AC, condensate, MAVS

I. INTRODUCTION

In air conditioner when the evaporator coil surface temperature is lower than the dew point temperature of the inlet air stream, condensation occurs over the surface of the coil. Normally a large capacity air conditioning systems operating in hot and humid areas generate huge quantities of condensate. When moist air is cooled below its dew-point by bringing it in contact with a cold surface some of the water vapour in the air condenses and leaves the air stream as liquid, as a result both the temperature and humidity ratio of air decreases. To quantify the amount of condensate generation is basically depend on the weather condition of the location, evaporator coil capacity and flow of air passing over the evaporator coil. In order to have an accurate prediction of the condensate production, detailed psychrometric analysis is required to determine the moisture content in the air under various conditions. In a typical air conditioning process, it is desired to condition a space to acceptable set values for temperature and humidity, referred to as the indoor design condition. In order to maintain this comfort condition, air is supplied to the space at a certain condition (SA). On the other hand, return air (RA) is extracted from the conditioned space and mixed with fresh air (FA) from the outside in a mixing chamber. This mixed air (MA) is then cooled by passing it over a cooling coil to achieve the require supply air condition. The amount of FA required depends on the space occupancy and application. So, the main factors that influence the amount of condensate collected are location (climate), building type (mainly the amount of outdoor air required) and sensible heat ratio (SHR). Adel Khalil [1] investigated the cooling and dehumidification air conditioning process as a possible technique for obtaining fresh water. The applicability of this method in climates where high temperature and relative humidity are encountered is investigated. Dusan Licina et al [2] investigated the potential for energy and water sustainability in hot and humid climates by utilizing the condensate captured from large dedicated air handling units (AHUs) for pre-cooling outdoor air in another AHU and subsequently offsetting cooling tower water needs. In such climates, latent load is large enough throughout the year to produce a substantial amount of condensate, which is typically drained away from all the AHUs. Amir Hossein Mahvi et al [3] conducted a study to evaluate the quantity and chemical quality of water obtained from Bandar Abbas air conditioners for the duration beginning of March to early December of 2010. Sixty-six samples were taken in cluster random plan. Bandar Abbas divided into four clusters; based on distance to shore and population density. Chemical tests which included: Turbidity, alkalinity, total hardness, Dissolved Solids (TDS) and Electrical Conductivity (EC) and quantity measurement were performed on them. Obtained water had slightly acidic pH, near to neutral range. Total dissolved solids, electrical conductivity, total hardness and alkalinity of extracted water were in low rate. Each air conditioner produced 36 Liters per day averagely. Split types obtained more water to window air conditioners. Esam Elsarrag et al [4] adopted two methods of collecting water from the atmosphere are presented. First by collecting condensate water, which is usually discarded, from existing air conditioning systems. Experimental measurements of water recovered from the atmosphere by existing air conditioning systems have been carried out. The average rate of condensed water collected during the experiments is found to be about 7.2 l/day per kW cooling. The experiments demonstrate a cost-efficient means of water recovery which can be implemented in air-conditioned buildings. Md. Arafat Ali et al [5] in their study carried out the experiments to assess generation of condensate water under different weather and operational conditions. The most important parameters affecting condensate water generation are time, difference between outdoor and indoor temperature and humidity.

II. METHODOLOGY

This module of research work deal with an extensive survey in Guwahati city about different aspects of split air conditioner along with its sale, use in hours. Analytical and experimental work is carried out to find out potential of condensate generation of 1.5-ton split air conditioner in the climatic condition of Guwahati city, India with and without MAVS. Further quality and quantity analysis of condensate is done for proper utilisation of condensate. For quality analysis chemical testings of condensate are done along with normal water and battery distilled water and the results are compared. For quantity analysis both analytical and experimental methods are followed ana validate with each other. For analytical method one mathematical too is developed in PYTHON. Further based on the sales of 1.5-ton split air conditioner forecasting of condensate generation for the next five years have been done. Looking at the colder temperature of condensate (140C-200C) experimental investigations have been performed to pre-cool the air before entering the condenser by using one pre cooler and condensate as coolant.

III. CONDENSATE QUANTITY AND QUALITY ANALYSIS

For the utility of condensate, it is important to know about the quality of condensate generation and the amount of condensate formed from a split air conditioner. Here some chemical testings, experimentation, observation, data collection has been performed for quality and quantity analysis of condensate.

A. Chemical testing of condensate, drinking water and distilled water

Three condensate samples (C1, C2, C3) of 1 litre each are collected in three new bottles from different location of Guwahati city namely Jalukbari, Panbazar and Kahilipara from three different 1.5-ton capacity split air conditioner. In the same way three samples of commercially available battery distilled water (D1, D2, D3) each bottle of 1 liter is collected from the market. Further three samples of drinking water (E1, E2, E3) are collected from different location as mentioned above. All the collected samples are tested chemically in the environmental laboratory, Civil Engineering department of Assam Engineering College following the procedure as mentioned in table 1

The chemical test was performed for individual samples separately and a comparative statement is made to differentiate the chemical properties of condensate water, drinking water and distilled water as shown in the table 2. The average value of the three samples for each item is considered for calculation. All the items i.e condensate, normal water and battery distilled water are tested chemically. The measuring parameters for quality analysis of the items were pH value; turbidity, TDS value and different mineral content in each sample are determined and compared with each other. Here C1, C2, C3 represents the condensate samples, D1, D2, D3, represents the distilled water samples and E1, E2, E3 represents three samples of normal water.

Table 1 Parameters measured during chemical testing of samples

Parameters measured	Method of determination	Reagent used	Formula used
1. Total hardness	Titration	1. EDTA solution ,0.01 M 2.Erichrome Black T indicator 3. Buffer solution 4. Sodium sulphide solution.	Hardness, mg/l= ml of EDTA used ×1000÷ml of sample
2. Calcium	Titration	1.EDTA solution 0.01M 2.Sodium hydroxide 1N 3.Murexide indicator	Calcium, mg/l= ml of EDTA used ×400.8÷ml of sample
3. Magnesium			Magnesium=(X-Y) ×400.8/Volume of sample×1.645 Where, X= EDTA used in hardness determination=EDTA used in Calcium determination.

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4. Chloride	Titration	1. Silver nitrate,0.02N 2.Potassium Chromate,5%	Chloride, mg/l=(ml×N) of silver nitrate× 1000× 35.5÷ml of sample
5. Sulphate	Titration	1. Dilute nitric acid 2. Standard barium chloride solution 3.Buffer solution 4.Erichrome black T indicator 5.Standard EDTA solution	Sulphates, mg/l= 9.6× (0.1 A+B - 4C) Where, A= total hardness of sample, B= Volume in ml of standard barium chloride solution, C=volume of standard EDTA solution required for titration of sample

In the table below average of C, D and E represents the average value of 3 samples of condensate, distilled water and normal water respectively. It is observed from the above chemical properties that the condensate generated from the air conditioners are almost equal to the value of commercially available battery distilled water in Guwahati city. Further as no microbial test are performed for the condensate it may contain high bacteria count in the condensate depending on the age of the AC and as well as with the climatic condition of the region. So, from the experimental observation there is a scope of utility of condensate as battery distilled water which has a huge demand in Guwahati city if it is well collected. Further already research has been done that it can be used in irrigation purpose as well as other house hold activity.

Table 2 Results of chemical testing of different parameters of the samples

Parameter	C1	C2	C3	Average C	D1	D2	D3	Average D	E1	E2	E3	Average E
pH	6.55	6.45	6.63	6.54	6.50	6.57	6.70	6.59	7.20	7.81	7.60	7.54
TDS (mg/L)	10.60	11.20	10.33	10.71	9.40	9.80	10.3	9.83	102.6	98.90	80.20	93.90
Total Hardness (mg/L)	7.80	8.10	7.60	7.83	6.70	7.10	6.80	6.87	94.30	98.40	90.50	94.40
Ca(mg/L)	1.64	2.46	1.876	1.99	1.60	2.00	2.10	1.90	49.64	51.20	45.65	48.83
Mg(mg/L)	0.98	1.26	1.10	1.11	0.98	1.10	1.46	1.18	37.72	40.52	41.21	39.82
Chloride (mg/L)	13.06	12.45	11.67	12.39	12.24	11.44	12.08	11.92	42.66	44.21	41.60	42.82
Sulphate (mg/L)	10.10	9.80	10.40	10.10	9.52	8.68	9.87	9.36	28.80	30.00	33.14	30.65
Alkalinity (mg/L)	19	17	20	18.67	16	18	19	17.67	70	85	120	91.67
Turbidity (NTU)	5.00	4.00	5.00	4.67	3	5	5	4.3	3	3	4	3.33

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IV. RESULT AND DISCUSSION

4.1 Condensate quantity analysis

The amount of condensate generated from a split air conditioner is totally dependent on the environmental condition of that region like ambient temperature, wet bulb temperature, due point temperature, relative humidity, capacity of evaporator coil, thermostat set point temperature performance of air conditioner. Guwahati being a warm and humid region there is a huge potential of condensate generation in this climatic condition. In this research work one attempt is made to find out the amount of condensate generation by a 1.5-ton split air conditioner throughout the year in the environmental condition of Guwahati city which is already been wasted till now and to forecast the probable recovery of condensate up to 2027 with analytical and experimental observation. As discussed in chapter four the amount of condensate generation is found in a typical day of each month for 24 hours of running of AC for following two cases
(A) Without fresh air
(B) With fresh air in every alternate 2 hours for duration of 2 hours.

4.1.1 Condensate quantity analysis by analytical method

In order to have an accurate prediction of the condensate production, detailed psychometric analysis is required to determine the moisture content in the air under various conditions. In a typical air conditioning process, it is desired to condition a space to acceptable set values for temperature and humidity, referred to as indoor design condition.

4.1.2 Development of mathematical tool for calculation of condensate

Based on the mathematical equations and psychometric chart the amount of condensate generation is found out as discussed above for both conventional split AC as well as split AC with mixed air ventilation system. It takes lot of time for calculation of amount of condensate for individual ambient temperature and RH. Taking in to consideration of the above aspect one user friendly mathematical tool has been developed using python programming language. The software used here is also python.org and is open-source software. Figure 1 shows the screen shot of the condensate calculator. In this calculator the values of T_{FA}, Θ_{FA} are required to put according to outside condition and from the psychometric chart the value of ω_{FA} is obtained. Similarly, the values of T_{RA}, Θ_{RA} are required to put according to inside design condition of the room and from psychometric chart the value of ω_{RA} can be obtained. Once those values including amount of fresh air are put in their respective places, the values of T_{MA}, ω_{MA} and H_{MA} can be obtained by the calculator. To obtain the value of T_{SA},ω_{SA} and H_{SA} the values of X, T_d and SHR are required to put and finally the amount of condensate(C) in L/hr is obtained.

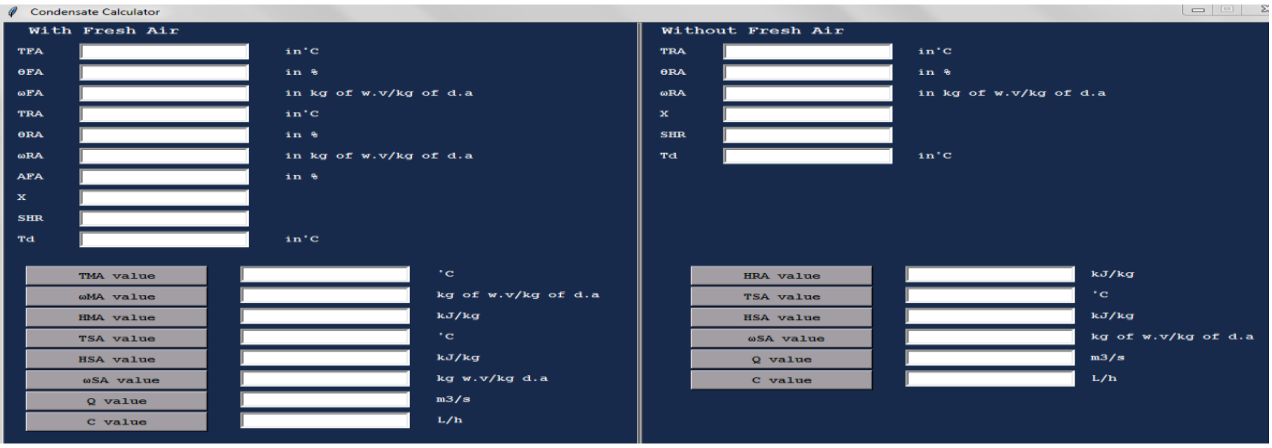

Figure 1 Screen shot of condensate calculator developed by using Python language

4.1.3 Condensate quantity analysis by experimental observation

Experimentation was carried out using two 1.5-ton split AC. The data collection of condensate generation is done on a specific date of each month throughout the year for both the case (A) and (B) as mentioned above. In the survey it was clear that in the climatic condition of Guwahati city user runs an AC for eight months of a year i.e from March to October. For experimental observation one specific day was considered for each month and the observation was made for 24 hours

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of the day. From survey it is found that in Guwahati most of the RAC used in residence run for both day and night time but the AC used for commercial area runs for day time only. In residence running time of AC in the night time is more than day time. From the readings taken it is clear that the humidity in the atmosphere is always much higher (70-85%) in the night time. Table 3 represents the amount of condensate generation in l/hr in hourly basis for 6 hours running in day time and 6 hours running in night time in a typical date of month of June in the year 2021 for case (A) and case (B) respectively. The experimental observation has been done for the last three years i.e from 2019-2022 for the eight months of running of AC throughout the year i.e from March-October. The readings were taken for five days a month at different weather condition of Guwahati city.

Table 3. Hourly rate of condensate yield in a typical day in August, Guwahati climate

Time	Dry bulb tempe-rature (˚C)	RH (%)	Experimental value of condensate (L/hr) without fresh air	Analytical value of condensate (L/hr) without fresh air	Experimental value of condensate (L/hr) with fresh air	Analytical value of condensate (L/hr) with fresh air
DAY						
10:00AM	33	75	-	-	-	-
11:00AM	32	75	2.2	2.4	2.2	2.4
Noon	34	85	1.9	2.3	1.9	2.3
1:00 PM	34	75	1.8	2.2	3.0	3.3
2:00 PM	34	70	1.5	2.3	2.8	3.1
3:00 PM	33	67	1.4	2.2	2.0	2.2
4:00 PM	34	69	1.2	2.1	1.6	2.3
NIGHT						
9:00 PM	33	82	-	-	-	-
10:00PM	32	77	2.3	2.5	2.3	2.5
11:00PM	31	79	1.9	2.0	1.9	2.0
12:00PM	29	79	1.5	2.0	3.2	3.5
1:00AM	29	84	1.1	1.9	2.6	3.1
2:00AM	27	90	1.5	2.2	2.1	2.2
3:00AM	28	89	1.7	2.5	1.9	2.4
Total(L)			20.00	25.50	25.70	31.40
Average			1.68	1.96	2.30	2.61

4.1.4 Comparison of experimental data with the analytical

The average condensate produced per day for each month from a 1.5-ton split AC for 12 hours of running have been shown in a typical day of August is shown in Table 4. In the same way for each month the experimental data were collected for three different days for duration of 12 hours, at day time 6 hours and night time 6 hours with (with F/A) and without fresh air (without F/A) and the average value of yield of condensate for each month has been shown in table 4.

Table 4 Month wise average yield of condensate (Liters/hour) for both the cases

Months	Without F/A	Without F/A	With F/A	With F/A
	Experimental Value(l/hr)	Analytical Value(l/hr)	Experimental value(l/hr)	Analytical Value(l/hr)
March	1.15	1.50	1.71	1.89
April	1.40	1.66	1.93	2.25
May	1.70	1.95	2.13	2.35
June	1.75	2.01	2.25	2.57

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July	1.83	2.15	2.47	2.70
August	1.85	2.21	2.50	2.79
September	1.80	1.99	2.40	2.69
October	1.60	1.81	2.10	2.38

The figure 2 shows a graph between experimental and calculated value of condensate per hour for different month without fresh air and with fresh air

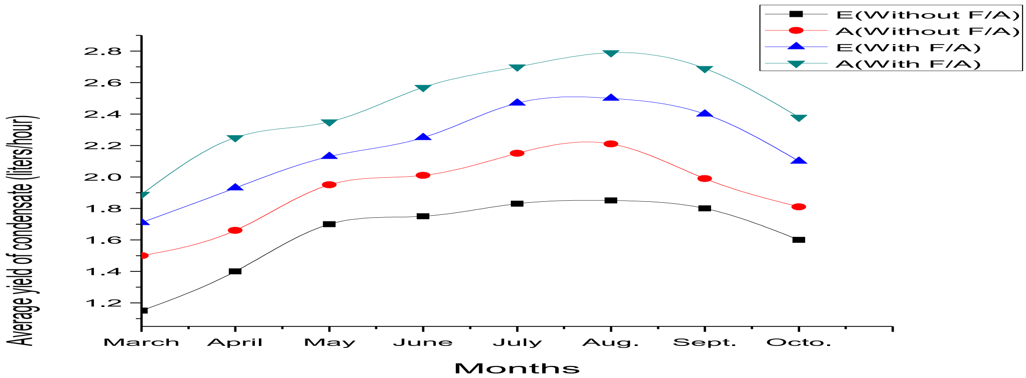

Figure 2 Yield of condensate from 1.5-ton split AC in Guwahati throughout the year

4.2 Forecasting of Condensate

Forecasting means the prediction of future data by gathering and analysing the past and present data. So, forecasting of condensate refers to the estimation of amount of condensate produced by the Air conditioners present in Guwahati city for the future on the basis of past and present data. The direct estimation of amount of condensate produced is somewhat difficult because there is no past data available regarding the amount of condensate produced in the whole Guwahati city. Therefore, based on the data of total no of AC for the past few years that had been sold in Guwahati forecasting of total number of AC to be sold for the upcoming few years can be done. From that the forecasting of condensate will be done. For the last four financial years sales of 1.5-ton split air conditioner is shown in table 5. Direct forecasting of condensate is quite difficult as till now date no one has attempted to recover condensate in Guwahati, thus total number of 1.5-ton AC sold in the next ten years is calculated by least square (linear regression) analysis is shown in table 6.

Table 5 Last four years sales of 1.5-ton split air conditioner in Guwahati

BRAND NAME	YEAR OF 2019	YEAR OF 2020	YEAR OF 2021	YEAR OF 2022
X1	1118	1199	2147	2897
X2	2452	3113	4578	4780
X3	810	1060	1420	1646
X4	1442	1778	2401	2480
X5	1439	1901	1221	1123
X6	406	678	886	1009
X7	192	301	435	465
X8	454	892	1227	1246
Total	8313	10922	14315	15646

For least square (linear regression) analysis

The general linear equation is Y= a + b X, where a, b are constants

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Table 6 Forecasting parameters for sale of 1.5-ton split AC in Guwahati city

Years (X)	Sales of A.C. (In numbers) (Y)	Deviation $X = X-\bar{X}$	X^2	X×Y
2019	8313	-1.5	2.25	- 12469.5
2020	10922	-0.5	0.25	- 5461
2021	14315	0.5	0.25	7157.5
2022	15646	1.5	2.25	23469
n = 4	∑Y= 49196	∑X = 0	$\sum X^2 = 5$	∑XY=12696

$a = \frac{\sum Y}{n} = \frac{49196}{4} = 12299.0$

$b = \frac{\sum XY}{\sum X2} = \frac{12696}{5} = 2539.2$

Y = 12299.0 + 2539.2 X

For 2023, X = 2.5, Y= 12299.0+2539.2×2.5 = 18647

For 2024, X = 3.5, Y=. 12299.0+2539.2×3.5 =21186.2

For 2025, X = 4.5, Y= 12299.0+2539.2×4.5 =23725.4

For 2026, X = 5.5, Y= 12299.0+2539.2×5.5 =26264.6

For 2027, X = 6.5, Y= 12299.0+2539.2×6.5 =28803.8

The numbers of sales of 1.5-ton AC for the next five years have been forecast by least square analysis or linear regression analysis. Now to estimate the maximum possible yield of condensate in the Guwahati city from 1.5 ton of air conditioner is shown in the following table 7.

Table 7 Month wise maximum possible yield of condensate with and without F/A

Months	Yield of condensate (litre/hour)		Average running time of AC (hours)	Monthly yield of condensate (Liters)	
	Without F/A	With F/A		Without F/A	With F/A
March	1.15	1.71	4	142.6	212.0
April	1.40	1.93	4	168.0	231.6
May	1.70	2.13	6	316.2	396.1
June	1.75	2.25	7	367.5	472.5
July	1.83	2.47	8	453.8	612.5
August	1.85	2.50	8	378.0	620.0
September	1.80	2.40	7	390.6	504.0
October	1.60	2.08	5	248.0	322.4
Total				2464.7	3371.1

From the table 7 it can be seen that based on the trend of average running hours of AC in Guwahati city maximum possible condensate yield by a1.5-ton split AC per year are 2464.7 L and 3371.1 L respectively with and without MAVS. By using this data and also by using the total yearly sales of AC, the total yearly amount of maximum possible condensate produced in entire Guwahati city from split air conditioners can be estimated as shown in figure 3.

Table 8 Forecasting of yearly condensate production

Years	Sales of 1.5-ton AC	Maximum yield of condensate (Liters)	
		Without MAVS	With MAVS
2019	8313	$2.04x10^7$	$2.80x10^7$
2020	10922	$4.74x10^7$	$6.48x10^7$
2021	14315	$8.26x10^7$	$11.31x10^7$
2022	15646	$12.12x10^7$	$16.58x10^7$
2023	18647	$16.72x10^7$	$22.87x10^7$
2024	21186	$21.94x10^7$	$30.01x10^7$
2025	23725	$27.79x10^7$	$38.01x10^7$
2026	26264	$34.24x10^7$	$46.86x10^7$
2027	28804	$41.37x10^7$	$56.57x10^7$

IV. CONCLUSION

From the above results and discussion, it is clear that condensate have a good potential to reuse for different household, industrial work which have been completely wasted in the Guwahati city, Assam. Two experimentations have been carried out one without fresh air i.e with normal 1.5-ton split air conditioner and another with a modified air conditioning system with mixed air ventilation system. Further in Guwahati city we have surveyed and find the exponential growth of sale of split air conditioners and based on that with linear regression analysis we forecast the sale of split air conditioners up to 2027. So based on that we can forecast the maximum yield of $41.37x10^7$ litres of condensate per year with normal split air conditioners and a maximum $56.57x10^7$ litres of condensate will be generated by the year 2027 and will be completely get wasted if not good planning is done for reutilization of condensate in Guwahati, Assam.

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