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AIR-CONDITIONING CONDENSATE RECOVERY IN HOT AND ARID CLIMATE REGIONS: A CASE STUDY

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ABSTRACT

In this study, we evaluate the implementation of the concept of wastewater reclamation in the air-conditioning system of an educative building located in a hot and arid climate region. In this building, Air-conditioning condensates are not reused; a fraction of this condensates is disposed to the municipal sewage network while the other fraction falls into roads causing localized water stagnation that leads to the reproduction of endemic vectors. On the other hand, lawn and garden areas in this building are currently irrigated with potable water. Here, as it has been reported by other authors, we found that the amount and quality of air-conditioning condensates make viable to use it for gardening. Moreover, we describe a renewable alternative to collect, dispose, and transport the air-conditioning condensates for later implementation in lawns and gardens irrigation.

Keywords: Air-conditioning condensates, wastewater reclamation, garden irrigation, water pumping, solar energy, photovoltaic.

1. INTRODUCTION

Wastewater reclamation is a promising alternative that may play a significant role to achieve sustainable development. One of the most promising applications to implement this concept is in air-conditioning systems [2], [3], [4]. It has been shown that air-conditioning condensates can be used directly in a variety of applications such as landscape irrigation, agriculture, recharge of aquifers, seawater barriers, industrial applications, systems for toilet flushing, and other urban uses [1], [5], [6], [7].

In hot weathers, especially, where a great amount of energy is used for air-conditioning (and therefore the higher levels of air-conditioning condensates are obtained) there is a considerable potential to save water and reduce buildings operation costs [2], [3], [4]. In fact, some municipalities have started to impose restriction on the use of potable water for irrigation of lawn and garden areas [2].

In this study, we evaluate the viability of using air-conditioner condensates for gardening in a hot and arid climate region. Although condensate recovery systems have been investigated in the past, recent studies agree that feasibility investigations are still needed because of regional restrictions and challenges that may arise in a particular operating environment [3].

2. MATERIALS AND METHODS

The study was performed in a three-level building with a build-up area of 8755 m^2, and 1505 m^2 of lawn and gardens. The building is located in a tropical urban area in Colombia (10°28'58.58'' N, 73°16'19.10'' W). Colombia's weather in this region is semi-arid, with average annual ambient temperature of 29°C and relative humidity of 65%. Thermal comfort in the building is achieved with mini-split units installed in each room. Generally, they are configured to operate at 22°C for 12 hours per day.

First of all, we performed an inventory of the air-conditioning units, focusing our attention in their refrigeration capacity. Three types of units are used in this building: 18K, 24K and 36K BTU/h.

NOMENCLATURE

Abbreviations		*Symbols*	
BTU	British thermal unit	A	Ampere
AC	Alternating current	C	Carbon
CAD	Computer assist draw	Ca	Calcium
DC	Direct current	cm	Centimeter
ETP	Evapotranspiration	h	hour
USA	United States of America	K	Kilo (x 10^3)
PV	Photovoltaic	L	liter
Impp	Max power point current	m	meter
Isc	Short circuit current	masl	meters above sea level
LEED	Leadership in Energy and Environmental Design	mg	Milligram
MPPT	Maximum Power Point Tracker	N	North
NPK	N: Nitrogen, P: Phosphorus, K: Potassium	O	Oxygen
NPSH	Net positive suction head	psi	pounds square inch
SD	Standard deviation	pH	potential of hydrogen
WHO	World Health Organization	rpm	revolutions per minute
PVC	Polyvinyl chloride	s	Second
VAC	Alternating current voltage	S	Siemens
VDC	Direct current voltage	V	Volts
Vmpp	Max power point voltage	W	Watts
Voc	Open circuit voltage	W	West
		µ	Micro (x 10^{-6})
		°C	Celsius

Data was collected for three months (September to November 2018). Moreover, we registered volumetric flow rate of condensates three times in a day and processed them using a simple ANOVA test. A total of 67 air conditioners were analyzed. On the other hand, different condensates samples were randomly selected to carry on physico-chemical analyses. Here, we present the results obtained for the following parameters: pH, conductivity, alkalinity, essential nutrients, Kjeldahl total nitrogen, total phosphorous and potassium. Orion Star A111-122 pH meters and conductivity meter determined pH and conductivity; alkalinity was determined by SM 2320B volumetric method; total phosphorous was determined by SM 4500-P B.E. photometric method, Kjeldahl total nitrogen was determined by SM 4500-Norg B / SM 4500-NH3 B, C - volumetric method; potassium was determined by SM 3030 K / SM 3500-K B spectrometer method. Hanna Instruments spectrophotometer was used for some essential nutrient tests.

Finally, considering all the results obtained from the tests describe above, we propose an automatic system that collect, dispose, and transport the air-conditioning condensates for later implementation in lawns and gardens. This system is based on PV pumping units.

3. RESULTS AND DISCUSSION

As described above, data were collected for three types of air-conditioner units: 18K, 24K y 36K BTU/h. The quantity of each one was 18, 22 and 27, respectively.

3.1 Rates and daily condensate production

All data recorded were analyzed by a one-way ANOVA test with a significance level $\alpha=0.05$. Fig. 1 shows the average volume of condensate obtained for the different time spans that were considered in each measurement session. The flow rate of condensate was 1.25 ± 0.012 L/h, 1.31 ± 0.01 L/h and 4.54 ± 0.07 L/h (mean ± SD) for the 18K BTU/h, 24K BTU/h and 36K BTU/h units, respectively. In other words, it is possible to have 2086.80 liters per day.

The methodology indicated in [8] was used to determine the theoretical production of air-conditioner condensates. The predicted values for the local climatic conditions are 1.48 L/h, 1.97 L/h and 2.95 L/h for 18K BTU / h, 24K BTU / h and 36K BTU / h units, respectively. Which are lower than the experimental results, especially for 18K and 24K BTU/h units. In [5] and [7], the authors concluded that when comparing experimental and theoretical results for the flow rate of condensates, the later tend to be higher than the former. This is due to the assumption of ideal operating conditions in the theoretical approach.

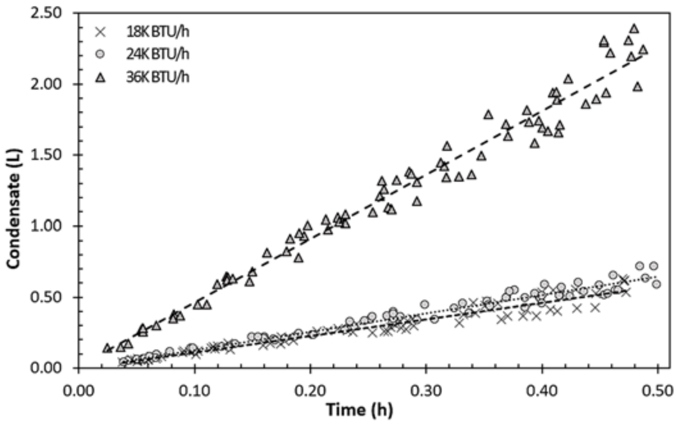

Fig 1. Volume rates production condensates per hour

3.2 Quality of condensate

Some of the studies reviewed in [5] consider using air-conditioning condensates for domestic purposes. Within the parameters of quality stands out the pH. As mentioned in [7], the WHO established a range of 6.5 to 8.5 for potable water. Here, the pH values obtained from the condensate samples was around 8.08. With respect electric conductivity, some studies report values from 0 to 400 µS/cm for domestic purposes [5]. Here, the electric conductivity values obtained from the condensate samples was around 133.78 µS/cm. The alkalinity was 21.5 mg $CaCO_3$/L.

Regarding the essential nutrients (NPK), in the referenced literature no values are specified for the irrigation of grasses or gardens. In [3] was reported feed 20 grams of fertilizer (NPK 20-20-20) to vegetable crops sprayed with condensates is reported in order to help the growth of seedlings after germination. It was obtained in this study for Total Nitrogen Kjeldahl 2.31 mg N / L, for total Phosphorus the detected concentration was <0.05 mg N / L and for Potassium <1.00 mg K / L. Result of condensate chemical analysis are reported in [7], which include turbidity, chloride, and nitrate. Likewise, it is referenced in some studies in [5] and dissolved oxygen values too.

Future studies can be developed to determinate optimum concentration of NPK on water for lawns and gardens irrigations.

3.3 Irrigation areas

According to [9] and due to the local ETP, we considered that an amount of 6 L/m^2 of water is needed for the irrigation process. Evaluating the amount of condensates that are projected to recover per day, these would be enough to cover the irrigation for an extension of 376.24 m^2, which represent 25% of the total area of gardens and lawns of the building.

3.4 Proposal of a system to use air-conditioning condensates for gardening

Condensates from climatization units should be conducted by gravity into store tank locate under plate first floor elevation. At inlet a by pass is configured to discharge the excess condensates to municipal storm pipe. The stored water will be available for irrigation works and a PV system will be coupled for the energy required by devices.

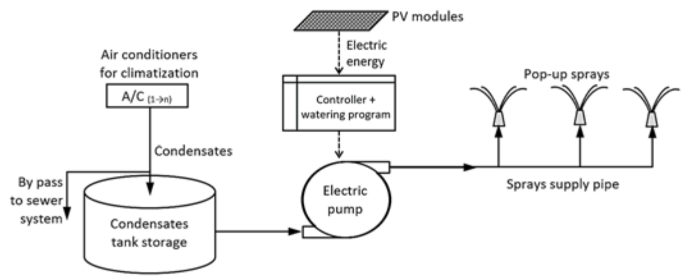

Fig. 2. Schematic of retrieving condensate for lawn and gardens irrigation driven by PV system

3.4.1 Irrigation system

It is proposed install twenty-three pop-up sprays, inlet size 1.27 cm (1/2") and operational pressure 21.09 meters of water gauge (30 psi), to cover both zone 1 and 2. The hydraulic design was conducted using Hazen Williams to determine loss pipe. Water velocity and flow was 1.8 m/s and 1.45 L/s. The PVC pipe sizing for sprays was 3.81 cm (1.1/2"), total dynamic head was 25.59 m and pump efficiency 65 %. Through the calculations was adopted a centrifuged electric single-phase pump 0.75 kW power, 110 VAC and 3500 rpm. The max suction head 4.70 m and net positive suction head available was 7.06 m, therefore cavitation will not cause damage to the pump impeller.

3.4.2 PV system proposed

The consumption loads and power of electric devices are listed in table 1. Tilt and orientation of PV modules are faced to capture the greatest amount of energy coming from solar rays. The study site is located geographically in north latitude, for this reason PV modules tilt fixed to 11° respect to horizontal. Orientation respect to magnetic south is fixed to -8°

towards west.

Table 1
Loads and power

Device	Quantity (un)	Power (W)	Use (h/day)	Consumption (Wh/day)
Pump	1	750	0.58	435
Controller, On (24 VDC - 1.4 A)	1	33.6	24	806.4
Valves, Off (24 VDC - 0.19 A)	2	4.6	23.42	215.46
Valves, On (24 VDC - 0.35 A)	2	8.4	0.58	9.74
Timer switch	1	4.5	24	108
	Total	801.1		1574.6

The solar irradiation used for calculations was 4.87 kWh / m^2 / day and the sunshine time was 6.5 hours per day. In this time energy produce by PV modules will charge batteries. Devices setup had been considered in some studies [10], [11].

Watering is considerate at night due to the high rate of ETP recorded during the day, in addition, by constant pedestrian circulation around the green areas.

Fig. 3 shows an off grid set up propose which allow both, autonomy and replicability of the system implementation for urban or rural areas with similar characteristics considerate in this study.

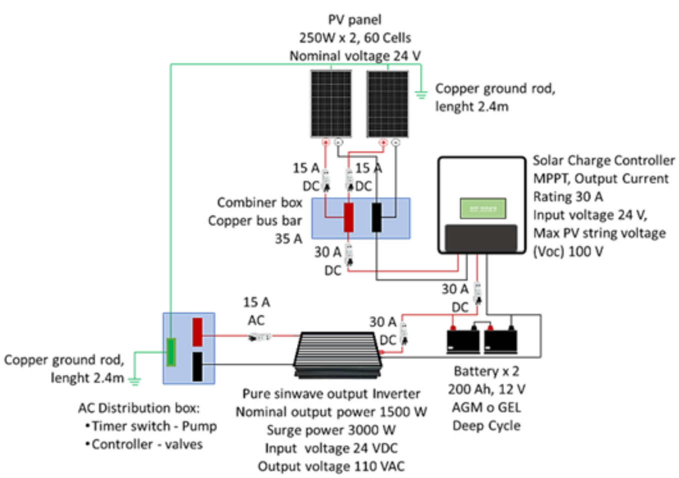

Fig. 3. Schematic of PV system

Source circuit will get parameters values listed in table 2.

Some studies considerate equipment that use DC due to the efficiency of these devices, for this reason, they not considered inverter setup proposed in them [10], [11], [12], [15]. Instead inverter allows system setup known as solar pumping, which makes possible to use equipment that works with CA [11], [13], [14], [15]. In this case, Fig. 4 shows scheme propose for this study.

Table 2
PV source circuit parameters

Parameter	Individual values	String values	Units
Impp	8.26	(8.26 x 2) 16.52	A
Isc	8.75	(8.75 x 2) 17.50	A
Vmp	30.30	(30.3 x 1) 30.30	V
Voc	38.00	(38.0 x 1) 38.00	V

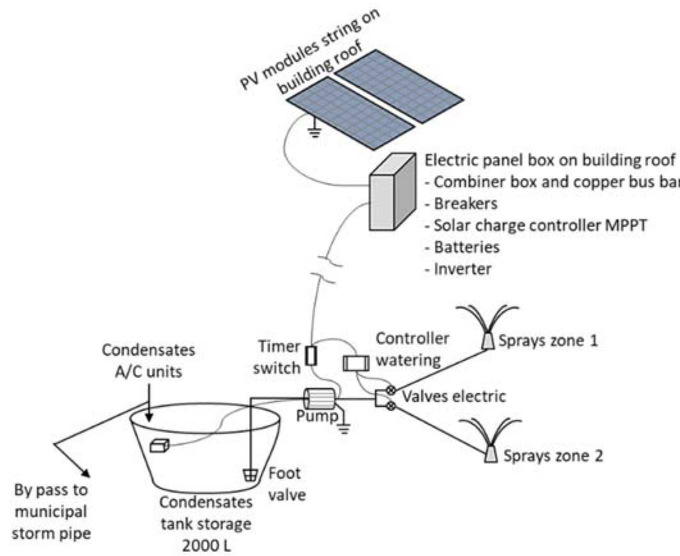

Fig. 4. Schematic of solar driven automatic irrigation system proposed

4. CONCLUSIONS

In this study, we evaluate the implementation of the concept of wastewater reclamation in the air-conditioning system of an educative building located in a hot and arid climate region. For the operating conditions and amount of air conditioners shown here, it was found that is possible to obtain around 2 m^3 of condensate per day (around 700 m^3 pear year). This result and the observations on important parameters such as pH and conductivity of the condensate samples allow to conclude that is possible to use air-conditioning condensates for gardening. In the case presented in this study was observed that up to 25% of the potable water that is currently use for gardening can be substituted by air-conditioning condensates. Another important conclusion that can be drawn from this study is that is possible to integrate renewables technologies to the air-conditioner condensate recovery.

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