ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

Conservation of Potable Water Using Chilled Water Condensate from Air Conditioning Machines in Hot & Humid Climate

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Abstract-The hot and humid climate offers a substantial environment for generations of condensate water through cooling coils of air conditioning machines. This waste can be utilized to diminish the use of considerable amounts of potable water. This paper presents a focus on conservation of potable water using condensate water generates during cooling and dehumidification process in the air conditioning machines. The cooling coil's condensate water from air conditioning machines goes wasted to municipal sewerage systems usually. A considerable amount of low temperature condensate water can be harvested and utilized in the commercial buildings having a large cooling capacity plant. This alternative source can be utilized in various drainage and irrigation applications to reduce the use of municipal potable water and saving the energy. The G+20 Floor building's HVAC system consisting fresh air handling units typically can produce 2600 liters condensate water in 24 hrs and 78000 liters in a month at an average summer outdoor conditions, which can be utilized to trim down the demand of potable water and saving a substantial amount of energy and reducing 0.54284 kg CO_2e per kWh carbon emission which results in reduction of carbon footprint.

Index Terms:-**Cooling & Dehumidification, Chilled Water Condensate, Energy Saving, Potable Water Saving, Water Conservation**

I. INTRODUCTION

The potable water demands are enormously curtailed by using the water conservation techniques, resulting in the postponement of water system expansion and protection of water supplies. Potable water which is commonly called as drinking water is the basic necessity for human beings without having any risk of any type of harm to health [1] . Water is the indispensable and life saving fluid for all living things including human beings and is thence critical for physical endurance [2].

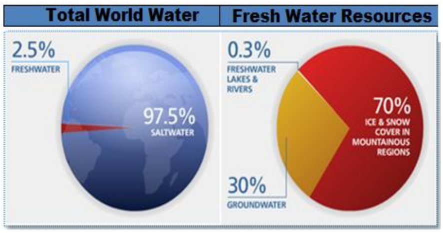

Fig 1 world water & fresh water resources

Despite the fact that most of the part of our earth is covered by water and is about 1.4 billion KM on earth, the freshwater resources are only 2.5% of this total volume which is merely 35 million km³ as illustrated in fig.1 [3].Resources are being consumed at an unsustainable rate. In order to maintain a contemporary lifestyle of an average European or North American for global population approximately 3.5 Earth Planet will be required [4]. Despite of the fact that millions of people have no access to drinking water and thus resulting in death of one child every 21 seconds due to the diseases caused by the use of dirty water, human beings are using natural resources at an unsustainable rate [5] . Keeping in view of the current potable water resources and world population growth rate, it is estimated that by 2030 about 47% of the world population will be dwelling in high water stress areas. The developing countries will be the most affected due to their highest population growth rate in the areas which are already under cute water stress having limited access to safe drinking water and without any adequate sanitation facilities [6]. In realization of this critical situation, it is mandatory not only to optimize the use of potable water but to devise different means and techniques to conserve it in order to improve an overall water management system. One way is rain water harvesting to encourage potable water savings in buildings [7]. Since the potable water access has been tremendously decreasing around the globe, rain water consumption is the best alternate resource to save the potable water and thus reducing the problems of the water availability [8]. Grey water is utilized to conserve the utilization of consumable water. This water is marginally polluted by human exercises and might be reused again after suitable treatment. The general utilization of treated grey water or reclaimed water essentially involves can flushing or/and garden watering. Grey water contributes to the protection of high caliber new water supplies and possibly diminishing the pollutant in the environment [9]. The composition of gray wastewater relies upon sources and installations from where the water is drawn, e.g. kitchen, restroom or laundry. The chemical compounds present start from family unit chemicals, cooking, washing and the piping. By and large, grey wastewater holds lower

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

levels of organic matter and supplements contrasted with common waste water [10]. A residential home can diminish its typical potable water consumption by 31% by utilizing grey water for irrigation and toilet flushing [11]. The air conditioning systems produce a significant measure of condensate water from the cooling coils in warm and muggy climates. Rather than emptying this water into the sewer system, this water might be gathered and used in different non-potable applications and can save a substantial amount of vigor (energy). The high sticky environment throughout June to September in countries like in the United Arab Emirates (UAE) offer a useful source for generation of considerable amount of condensate through cooling and dehumidification of the cooling coils of air conditioning machines particularly from fresh air handling units. The Relative Humidity (RH) level of outside air arrives at above 90% throughout summer as shown subsequent UAE five years June – July 2007-2011 outside weather data [12] in figs.2 & 3 which is valuable to produce significant amounts of condensed water. International standards, national standards and local authorities' regulations have seriously started to focus on the utilization of chilled water condensate. The ANSI/ASHRAE/UGBC/IES Standard 189.1 (2011) [13] described on condensate harvesting in clause 6.3.2.3.c that building projects located in regions where the ambient mean coincident wet bulb temperature at the 1% design cooling conditions is greater than or equal to 22^{o}C (72^{o}F) shall have a system for collecting condensate from air-conditioning units with a capacity greater than 19 kW (65000 Btu.h^{-1}) and the condensate shall be recovered for reuse. The standard explain further that this condensate can be collected and reused as make-up water, as it is usually clean and cold. This can save water and improve system efficiency because of its cleanliness and lower temperatures. The Green Building Regulations & Specifications, DEWA, Dubai Municipality, Government of Dubai in line with the Dubai Strategic Plan 2015 [14], and directives for applying green building specifications on all buildings in the Emirate of Dubai UAE. Specification explained in the section 601, Chapter 1: Conservation and Efficiency clause 601.03 Condensate Recovery that for all new buildings with a cooling load equal to or greater than three fifty (350) kilowatt (kW), condensate water from all air conditioning equipment units handling outside air, or a mixture of return air and outside air where the outside air is not preconditioned, must be recovered and used for irrigation, toilet flushing, or other on-site purpose. Estidama New Buildings Guidelines (ENBG) [15] in the Emirate of Abu Dhabi, UAE offer a more sustainable holistic approach to sustainable building design. Estidama guidelines described in chapter 3: Water, clause 3.4 Water Reclamation, sub clause 3.4.3 that Air conditioning condensate in the normal operation of air conditioning equipment in warm, humid climates produces condensate water from the cooling coils. Rather than draining this water into the sewer system, this water may be captured and reused for other non-potable purposes. The condensate from air conditioners, dehumidifiers, and refrigeration units can provide facilities with a steady supply of relatively pure water for many processes. The building designs should therefore whenever practicable, incorporate condensate capture devices. The U.S. Environmental Protection Agency's Sustainable Facilities Practices Branch [16] has developed a top ten water administration strategy that has demonstrated obliging in supervising water utilization. The utilization of condensate water is one of their viable procedures. EPA's Environmental Services Branch Laboratory located in Houston, Texas, USA has enabled a task that incorporates air handler condensate recuperation at an expense of less than $6,000. This project saved the laboratory $20,000 over the past six years and additionally recovers around 832,000 gallons of water annually. The Region 4 Science and Ecosystem Support Division Laboratory in Athens, Georgia, USA completed a venture in 2008 to capture condensate from three roof top air handlers and directed it to cooling tower to use as makeup water. The project saved around 300,000 gallons per year. EPA developed a water management plan for Science and Ecosystem Support Division (SESD) [17]. EPA used $24,500 reporting in real time handler condensate recuperation project incorporating the establishment cost of a flow meter to measure all out gallons recovered. The venture safeguarded more than 540,000 gallons of water from May to December 2008 which was about 16 percent total reductions in overall water utilization. This water saving is esteemed at $3,500 at a rate of $6.52 for every thousand gallons of water. The framework additionally enhanced cooling tower water chemistry and it is expected to decrease general chemical treatment expenses because of the almost nearly-pure recovered condensate water. Water Efficient Building Design Guide [18] developed by PUB, the National Water Agency Singapore, states in chapter-2: Designing a Water Efficient Building (section 2- 4: Choose Water Efficient Cooling System) sub section-III p-19-20: Use of Non-potable Water for Cooling Towers that It is not always necessary to use potable water in cooling tower systems. The use of alternative water sources e.g. NEWater, condensate water, etc. shall be considered. NEWater should be used as make-up water for cooling towers if available. NEWater enables a higher concentration cycle and better water efficiency. Condensate could be gathered and reused as make-up water, as it is usually clean and cold. This can save water and enhance system efficiency because of its cleanliness and coolness. The Green Building Design Guide [19] developed by Building Construction Authority-Singapore. In guide Chapter-3. Water Efficiency, section 3.4 Cooling Tower Water Consumption,

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ISO 9001:2008 Certified
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sub clause 3.4.1 Use of Newater p 34-35 states that condensate water from AHUs or FCUs could also be utilized for cooling tower make up water. Using condensate water from the air side to top up cooling tower water not only lowers its water temperature to raise chiller efficiency, it also helps to reduce the amount of makeup water needed. The author elaborated on the yearly condensate gathering in his article 'Capturing Condensate by Retrofitting AHUs' [20] .

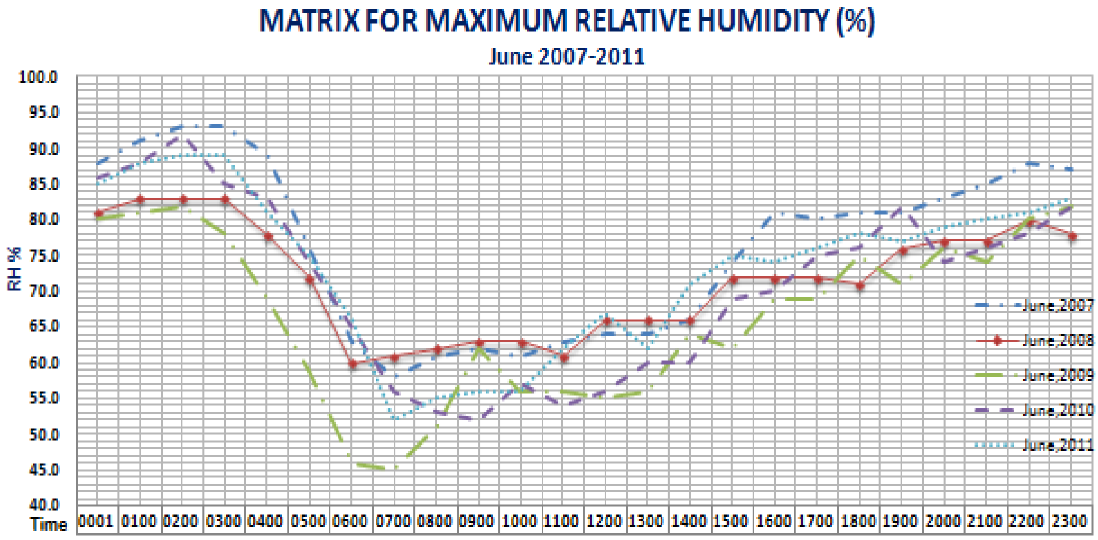

Fig 2-RH level June 2007-2011

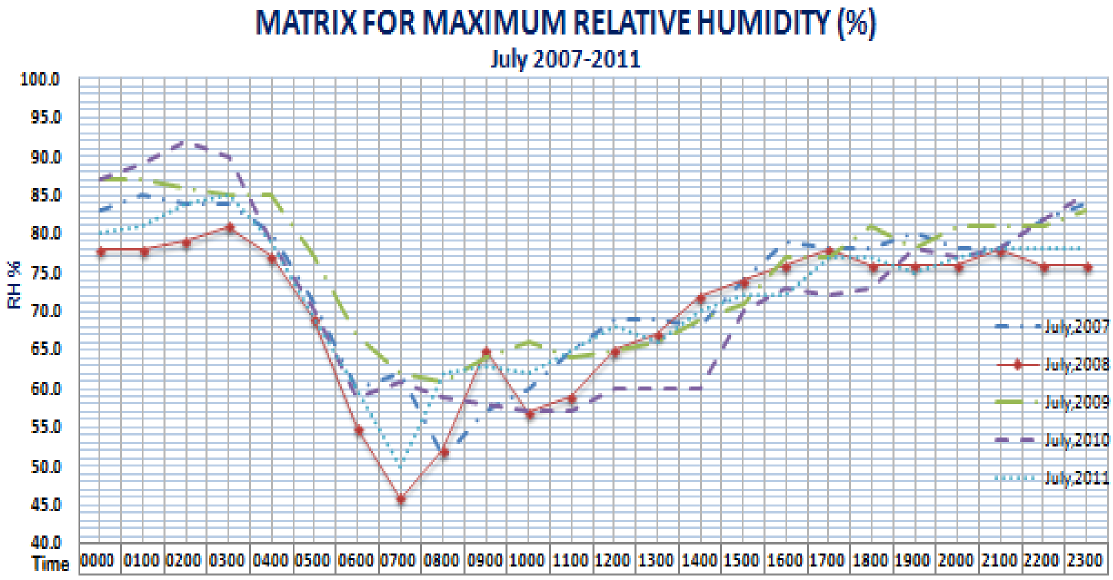

Fig 3-RH level July 2007-2011

The writer depicted in the article that a system designed and installed in UGA's College of Veterinary Medicine is forecasted to produce 450,000 gallons (1.7 million L) of condensate for every year. Utilizing the consolidated supply and sewer utility rate of \$0.0075/gallon (\$0.002/L), the system will save \$3,375 per year. The framework installation expense was \$3,200 and the simple payback is expected to be less than a year. Gregory R. Johnson described in the article 'HVAC systems in a typical laboratory facility' [21] that with the utilization of high amounts of outside air and 24 hours for every day operation, the cooling coils in the laboratory facilities can furnish a significant source of condensate water, which might be utilized for a mixed bag of purposes including irrigation or a non-potable water supply for toilet flushing and/or cooling tower makeup. The author depicted that recently built laboratory in Atlanta, 4 Nos. 14 158 $L.s^{-1}$ (30,000 cfm), 100% fresh air handling units were located in a penthouse. Utilizing weather bin data information and an estimated cooling load profile, the evaluated condensate recuperation from the cooling from the cooling coils exceeded 3028330 L (800,000 gallons) every year. Tom Lawrence, Jason Perry [22] outlined that developed nations

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

are realizing that condensate water from cooling coils of air conditioning machines should be treated as a valuable commodity and as important as energy. The authors compared annual expected condensate production rate is about 50.35 L (13.30 gallons) per cfm for the various cities like Athens, Ga., San Diego, and Phoenix etc. Karen Guz [23] brought attention in his article for successful condensate harvesting. Projects capturing air-conditioning condensate in San Antonio have assented shocking amounts of water. The downtown mall generates 946 L (250 gallons) each day from its air handlers. A central library system produces 0.06 $L.s^{-1}$ (1.0 gpm) or 163 530 L (43,200 gallons) for every month. He concluded, the best news about air-conditioning condensate recovery in all of these places is that water is produced as a natural by-product during periods of high heat and humidity when it is most needed. [23] developed a rule of thumb for large buildings in the summer months of 0.4–1.1 liters (0.1 to 0.3 gallons) of condensate per ton of air conditioning for every hour that the cooling system operates. Wilson [24] highlighted that the air-conditioning condensate recuperation is more pragmatic in hot and moist climates. He explained that large cooling plant those installed in enormous commercial buildings produced a huge amount of chilled condensed water which might be a major source to serve the landscape irrigation or a significant share could be utilized make up water for cooling towers. John & Ahmed [25] reported on condensate water harvesting for an Institutional Building in Doha, Qatar. The objective of the work was to monitor the condensate production of air handling units serving a classroom/laboratory building on the education city campus in Doha, Qatar. The air conditioning and ventilation for this building is supplied through 25 separate roofs mounted air handling units. The two AHUs systems frameworks were picked for monitoring and condensate collection. During the process maximum ambient air temperature observed was about 45°C (113°F) in the summer and 25°C (77°F) in the winter. [25] Demonstrated that the capture of condensate water was over 6 million liters (1.6 million gallons) of condensate water every year from the 2110 kW (600 Tons) air conditioning installed systems for this building. The above is a snap shot of work conducted on condensate's harvesting. The consequent methodology gives outcomes on narrow analysis basis and utilize condensate to conserve the considerable amounts of potable water.

II. METHODOLOGY

A. Theoretical Approach

High rise buildings in a hot and humid climate use dedicated treated fresh air along with re-circulated air conditioning system generally. The various states of the UAE such as Dubai, Abu Dhabi, Sharjah etc., has a large number of high rise buildings. The air-conditioning and ventilation schemes consist of DX split/package or water cooled air conditioning units along with 2-3 treated fresh air handling units depending upon the load used to maintain the indoor air quality (IAQ) of the building. The air conditioning system produces significant condensate water during the cooling and dehumidification process. It can be used to conserve the potable water .This; will focus on fresh air which gives a significant amount of condensed water during summer and mild seasons. Assuming, the G+20 floor residential building having 2 nos 24 hrs operation treated fresh air handling units of 4600 $l.\ s^{-1}$ (4.6 $m^3.s^{-1}$) each as per the following calculation furnished referring ASHRAE Standard 62.1 Ventilation rates [26] as shown in table fig.4. The total 9200 $l.s^{-1}$ treated fresh air will be required for maintaining the indoor air quality (IAQ) of inside building and avoiding sick building syndrome(SBS).In principle 2 Nos. treated fresh air handling unit will be proposed to treat the air which can generate significant amount of condensed water. At the average Dubai weather outdoor conditions as shown in table fig.5 for the month of July extracted from HAP Carrier HVAC Software program [27] and considering cooling coil outlet temperatures of 12.77°C (dry bulb) and 12.22°C (wet bulb), the condensate water hourly calculation were carried out. The cooling coil outlet air temperatures are determined to be ideal (for this climate) for removing the latent load of fresh air effectively during the cooling and dehumidification process. The calculation shown the condensate generation is about 78000 liters in 30 days, 2600 liters in 24 Hrs and more than 100 liters in an hour as detail showed subsequent in fig.6. Equation (1) is used for condensate calculation form cooling coil using specific humidity data generated by the ASHRAE psychometric analysis program [28].

$$m_w = V\rho\,(w_{\text{outdoor air entering cooling coil}} - w_{\text{cooling coil leaving air}}) \ldots (1)$$

This is a quite significant result of condensate water generated through FAHUs.

G+20 Floors Residential Building-Extract/Fresh Air Management							
Bed Room Type	Kitchen ($l.s^{-1}$)	Bath-1 ($l.s^{-1}$)	Bath-2 ($l.s^{-1}$)	Sub Total ($l.s^{-1}$)	Qty (Nos)	Total($l.s^{-1}$)	Operation
2 Bed room	24	12	12	48	3	144	Continuous
1 Bed room	24	12		36	5	180	Continuous
Studio	24	12		36	2	72	Continuous
Total/floor						396	
G+20 Floors Total Extract air 396 x 21						**8316**	
G+20 Floors Total Fresh Air with 10% for Pressurization 8316 x 1.10						9147.6	
G+20 Floors Total Final Fresh Air 9147.6 Say 9200						**9200**	

Fig 4-Fresh air and Extract air flow-ASHRAE Standard 62.1

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

Out Side Air Psychrometry Properties-Average July Dubai Weather Data											
Time	V	DB	WB	RH	W	V	H	DP	D	VP	AW
0000	4600	33.7	21.7	34.4	11.3	0.88	62.93	15.9	1.1290	13.546	12.808
0100	4600	33.2	21.5	35.4	11.3	0.88	62.37	15.9	1.1309	13.522	12.806
0200	4600	32.7	21.5	36.9	11.5	0.88	62.24	16.1	1.1325	13.709	13.005
0300	4600	32.3	21.3	37.6	11.4	0.88	61.68	16.0	1.1341	13.639	12.955
0400	4600	32.0	21.2	38.1	11.4	0.88	61.33	16.0	1.1353	13.620	12.950
0500	4600	31.9	21.2	38.5	11.4	0.88	61.33	16.0	1.1356	13.669	13.001
0600	4600	32.1	21.2	37.8	11.4	0.88	61.33	15.9	1.1350	13.571	12.889
0700	4600	32.6	21.4	37.0	11.4	0.88	62.03	16.0	1.1330	13.658	12.961
0800	4600	33.5	21.6	34.9	11.3	0.88	62.72	15.9	1.1298	13.553	12.823
0900	4600	34.8	22.0	32.5	11.4	0.89	64.15	15.9	1.1250	13.594	12.808
1000	4600	36.2	22.4	30.1	11.4	0.89	65.59	16.0	1.1199	13.597	12.752
1100	4600	37.9	22.9	27.6	11.4	0.90	67.43	16.0	1.1137	13.640	12.723
1200	4600	39.4	23.3	25.4	11.4	0.90	68.92	16.0	1.1084	13.618	12.642
1300	4600	40.6	23.6	23.7	11.4	0.90	70.05	15.9	1.1042	13.573	12.552
1400	4600	41.4	23.8	22.7	11.3	0.91	70.81	15.9	1.1015	13.546	12.495
1500	4600	41.7	23.9	22.4	11.4	0.91	71.20	15.9	1.1004	13.583	12.517
1600	4600	41.4	23.8	22.7	11.3	0.91	70.81	15.9	1.1015	13.546	12.495
1700	4600	40.7	23.6	23.5	11.3	0.90	70.05	15.9	1.1040	13.524	12.503
1800	4600	39.6	23.3	24.9	11.3	0.90	68.91	15.9	1.1079	13.521	12.543
1900	4600	38.4	23.0	26.7	11.4	0.90	67.79	15.9	1.1120	13.572	12.640
2000	4600	37.1	22.6	28.5	11.3	0.89	66.31	15.8	1.1168	13.504	12.629
2100	4600	36.0	22.3	30.3	11.3	0.89	65.22	15.9	1.1207	13.522	12.690
2200	4600	35.1	22.1	32.1	11.4	0.89	64.51	16.0	1.1239	13.618	12.818
2300	4600	34.3	21.8	33.2	11.3	0.89	63.43	15.8	1.1270	13.499	12.739
Cooling Coil Leaving Air Psychrometry Properties											
Cooling Coil	V	DB	WB	RH	W	V	H	DP	D	VP	AW
	4600	12.8	12.2	94.0	8.7	0.82	34.72	11.8	1.2168	10.405	10.558

Fig 5 Air Psychrometric data using ASHRAE Psychrometric analysis program

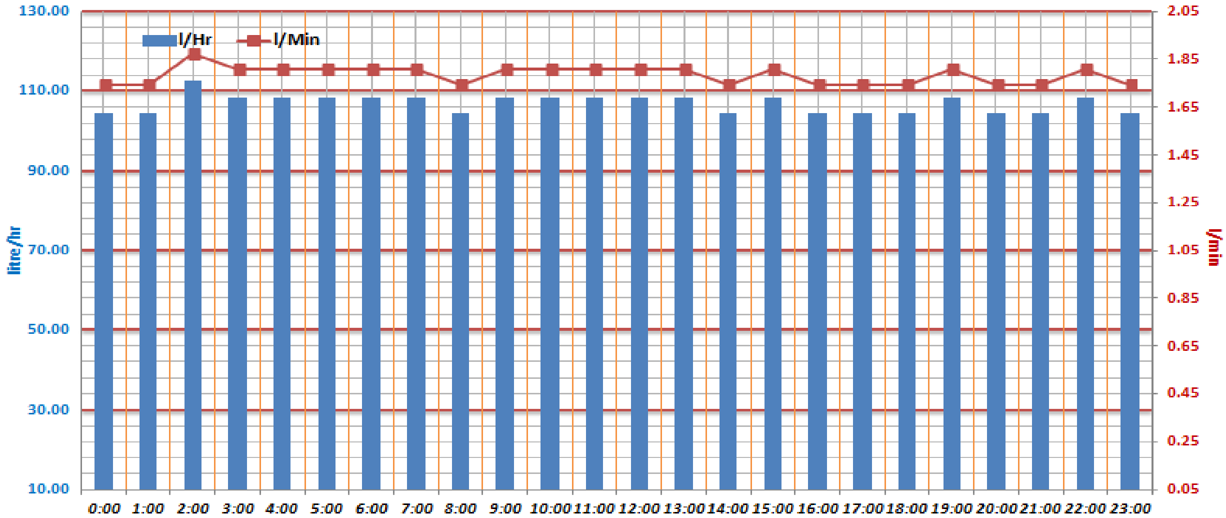

Fig 6-Condensate Water from FAHU's Cooling Coil at average Dubai outside Conditions for Month July

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 2, August 2013

The rate of condensate generation will vary as per the outdoor conditions. The sample calculation given is for July, while other summer months will give condensate generation output is more or less the same. This condensate water can be harvested and utilized to save energy and utilize this alternative source in various drainage irrigation applications to reduce the use of municipal potable water. The use of condensate low temperature energy my also benificail in saving the energy.

III. CONCLUSION

In the light of the above, the more use of potable water will be more expensive in the Arabian Gulf region as it is not available free. It is processed and then delivered to consumers. In Dubai, DEWA [29] has estimated the average monthly residential water demand to be 16.4 million m^3 for their 267,492 residential connections, or approximately 61.3 m3per connections per month. The price of the tap water is 4 Fills (0.04 AED) per gallon if use is more than 45425 litres (12,000 gallons) in a month. Therefore, around 78000 liters/month (20605 gallons/month) the chilled water condensate can be utilized as an alternative source in various drainage and irrigation and HVAC application such as cooling tower makeup water to reduce the use of municipal potable water eliminate the cost of potable water of about AED 825/month and can reduce power consumption of potable water pumps and reducing 0.54284 kg CO_2e per kWh carbon emission [30] thus the smaller carbon footprint. Looking at the upcoming energy and environmental challenges, this energy will play a very important role in saving energy. This free and green energy is being wasted. This opportunity must be used and will be a step towards sustainability.

IV. NOTATIONS

ρ	*Density of air, 1.2041 kg/m3 at 20°C*	*$kg.m^{-3}$*
w	*Specific humidity of air*	*$g.kg^{-1}$, $kg.kg^{-1}$*
h	*Specific enthalpy of air*	*$kj.kg^{-1}$*
RH	*Relative Humidity*	*%*
v	*Specific volume*	*$m^3.kg^{-1}$*
V	*Volume flow of air*	*$m^3.sec^{-1}$, $l.s^{-1}$*
mw	*Mass of condensate water*	*$l.hr^{-1}$, $l.min^{-1}$, $kg.s^{-1}$*
Q	*Power/Cooling Capacity*	*kW, W*
DP	*Dew Point Temperature*	*°C*
DB	*Dry Bulb Temperature*	*°C*
WB	*Wet Bulb Temperature*	*°C*
vP	*Vapor Pressure*	*mm Hg*
AW	*Absolute Humidity*	*$g.m^{-3}$, $kg.m^{-3}$*

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