# Energy Recovery Through the  Condensate of Air Conditioning Machines

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# Energy Recovery Through Air Conditioning Machine's Condensate

Shahid Ali Khan
Heriot-Watt University, Dubai Campus,
PO Box 294345, Dubai, United Arab Emirates

Fan Wang
Heriot-Watt University, Edinburgh, EH144AS,
United Kingdom

Sarim Naji Al-Zubaidy
MTC, PO Box 262, Postal Code 111,
Muscat, Oman

**Abstract** - ***The hot and humid climate requires the use of air conditioning machines almost all year round. An extensive amount of low temperature condensate water can be harvested through the commercial and residential high rise building's large cooling capacity plant. The research reported that this alternative source could be estimated the amount of chilled water condensate that is generated during the cooling and dehumidification process in the air conditioning machines.***

***The paper demonstrated that considerable amount of condensate water 368.0 l.Hr$^{-1}$ mean 1.5 liters. Hr$^{-1}$/ kW $_{latent\ cooling\ capacity}$ can be collected through fresh air handling unit (FAHU) being used in multi floors building of Ground +15 floors building and utilized for the pre cooling of associated recirculated air conditioning machines. The cooling capacity saving 15 percentage (%) and power input by 18 percentage (%) can be achieved by pre cooling the condenser's out door entering air. Total saving of AED 3240($910)/month can be attained through the FAHU of this multi floors building.***

**Keywords**

***Air conditioning, Air Psychrometry, Condensate, Cooling & Dehumidification, Energy Reclamation.***



## INTRODUCTION

The hot and humid climate of United Arab Emirates (UAE) customs central air conditioning machines for virtually the whole year. Air-conditioning consumes around up to 65 per cent (%) of total power consumption during summer and the highest source of greenhouse gas emissions in the Emirate. It is not limit to Gulf countries. As a whole, energy demand has rapidly increased globally. Energy consumption is being increased day by day. Global energy demand is being projecting to rise by over one-third in the period to 2035 [1] as can be seen in the subsequent *Fig.1*.It is rising from 6030 Mtoe to 16730Mtoe.

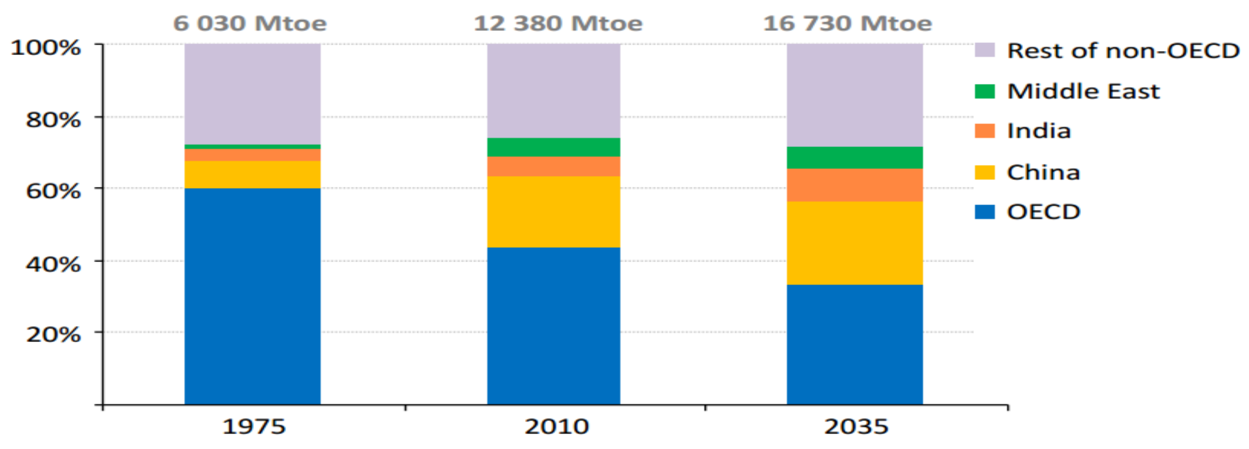


Figure1. World Energy Outlook 2012

The encouragement of energy efficiency and recoveries is one of the key goals of energy policies since it gets better resource management and reduces energy use and its environmental impact [2].

The substantial amount of condensate water through cooling coils of air conditioning machines is generated and is typically wasted to municipal sewerage systems. This energy can be utilized in air conditioning application for enhancing cooling plant efficiency, saving energy and reducing the carbon footprint.

The various energy standards have been introduced as necessary tools for improving energy efficiency and minimizing energy consumption in buildings like US ASHRAE Standard 90.1 [3], UK Building Regulations[4] Part L2A [4] etc.

The use of various energy recovery techniques [5] and devices like heat pipe [6],desiccant energy recovery wheel [7], use of VAVs [8,9], VSDs [10] and VRF [11] arrangements etc. have started in the HVAC industry to save the energy and the operational energy cost, reducing the carbon foot print and keeping the environment green & sustainable. The VRF multi-split system is also one of the practices of decreasing the quantity of energy used. Aynur [11] detailed review focuses on the main study of multi-split VRF system energy saving.

Elsayed and Hariri [12] presented an experimental investigation to study the performance of a direct expansion air conditioning unit having variable speed condenser fans. The authors found 10 per cent (%) reduction in compressor power consumption was achieved by increasing the condenser air flow by about 50 per cent (%).

Ciro [13] et al presented the results of experimental analysis performances of refrigeration capacity attained by means of a variable-speed compressor with the on/off control using thermostat control. Ciro et al concluded in their results that it is possible an average electric energy consumption of about 12 per cent (%) can be saved when an inverter is employed to control the compressor refrigeration capacity instead of imposing on/off cycle conventional thermostatic control working at the nominal frequency of 50 Hertz (Hz).

Amarnath and Blatt [14] described that multi-split VRF systems could save up to 30–40 per cent (%) of the energy by using a chiller-based system for a 200 refrigeration ton cooling system in a generic commercial building.

ElSherbini and Maheshwari [15] explained in his article that shading is also a technique which is used to reduce the cooling demand in buildings and save energy.

Hajidavalloo et al. [16] explained that increasing the coefficient of performance of an air conditioner with an air-cooled condenser is a challenging problem especially in areas with very hot weather conditions. Application of an evaporatively cooled air condenser instead of an air-cooled condenser is proposed in this paper as an efficient way to solve the problem. The power consumption can be reduced up to 20 per cent (%) and the coefficient of performance can be improved around 50 per cent (%).

Hajidavalloo [17] reported in another article, that the effect of using evaporative cooler in the window-air- conditioner by injecting water on the media pad installed in front of the condenser entrance.

He reported a 16 per cent (%) reduction in power consumption and a 55 per cent (%) improvement in total performance. The chilled water condensate from air conditioning machines is another one of the considerate energy recovery techniques to save the energy.

Literature review focused that various techniques are being used for energy saving. Condensate from A/C machines is being wasted. It is a good free source of energy recovery. It can be used for the condenser entering air pre cooling of air conditioning machines and can save considerable amount of energy by consuming a little infrastructure cost.

The international and national standards and local authorities have seriously started focusing on the use of chilled water condensate.

The ANSI/ASHRAE/UGBC/IES Standard 189.1 (2011) [18] clause 6.3.2.3.C, The Green Building Regulations & Specifications, DEWA, Dubai Municipality, Government of Dubai [19] clause 601.03 Condensate Recovery, Estidama [20] New Buildings Guidelines (ENBG) Abu Dhabi Chapter 3: clause 3.4.3 Air Conditioning Condensate, U.S. Environmental Protection Agency [21], Green Building Design Guide [22] Singapore, Chapter 3, Water Efficiency, clause 3.4.1 emphasis on the practice of chilled water condensate.



The amount of condensate water generation from air conditioning machines is a potential in hot and humid climates particularly in UAE as demonstrated subsequent in Table 1. The six (6) years data has been taken from Dubai Air Navigation Services [23] and the matrix generated from January to December to evaluate the outdoor air relative humidity (RH) level. The results validate that the outside air RH level was high during the morning, evening and night times throughout the years.

| years/hours | 0001 | 0100 | 0200 | 0300 | 0400 | 0500 | 0600 | 0700 | 0800 | 0900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan 2007 - 12 | 92 | 93 | 93 | 94 | 94 | 92 | 85 | 77 | 74 | 72 | 72 | 74 | 75 | 75 | 79 | 81 | 83 | 83 | 82 | 83 | 84 | 87 | 90 | 91 |
| Feb 2007 - 12 | 89 | 90 | 92 | 95 | 95 | 92 | 87 | 75 | 66 | 68 | 68 | 69 | 68 | 69 | 74 | 78 | 79 | 81 | 85 | 86 | 86 | 86 | 87 | 89 |
| Mar 2007- 12 | 91 | 92 | 93 | 93 | 93 | 87 | 81 | 74 | 71 | 69 | 67 | 72 | 66 | 68 | 73 | 82 | 81 | 84 | 81 | 82 | 83 | 85 | 86 | 89 |
| April 2007-12 | 89 | 91 | 91 | 90 | 88 | 78 | 64 | 62 | 60 | 58 | 56 | 63 | 62 | 65 | 67 | 74 | 77 | 78 | 79 | 79 | 82 | 83 | 85 | 85 |
| May 2007 -12 | 85 | 87 | 87 | 87 | 80 | 66 | 53 | 50 | 49 | 52 | 53 | 56 | 58 | 60 | 63 | 70 | 71 | 71 | 74 | 73 | 76 | 78 | 80 | 84 |
| June 2007-12 | 85 | 87 | 88 | 86 | 80 | 71 | 60 | 55 | 57 | 60 | 59 | 59 | 62 | 61 | 65 | 70 | 73 | 76 | 77 | 78 | 78 | 79 | 82 | 83 |
| July 2007 -12 | 83 | 84 | 85 | 85 | 80 | 71 | 60 | 55 | 58 | 62 | 61 | 63 | 66 | 66 | 68 | 72 | 75 | 77 | 77 | 77 | 78 | 79 | 80 | 81 |
| Aug 2007 -12 | 79 | 81 | 81 | 80 | 75 | 69 | 56 | 55 | 57 | 58 | 59 | 61 | 62 | 65 | 69 | 70 | 72 | 71 | 72 | 74 | 76 | 78 | 77 | 79 |
| Sep 2007 - 12 | 88 | 88 | 89 | 90 | 88 | 76 | 66 | 56 | 57 | 60 | 59 | 61 | 64 | 66 | 71 | 77 | 77 | 77 | 77 | 79 | 79 | 81 | 82 | 85 |
| Oct 2007 - 12 | 88 | 90 | 91 | 93 | 92 | 81 | 71 | 62 | 58 | 56 | 59 | 62 | 63 | 69 | 72 | 73 | 75 | 75 | 75 | 77 | 78 | 82 | 86 | 86 |
| Nov 2007 -12 | 75 | 78 | 80 | 80 | 80 | 75 | 69 | 61 | 58 | 58 | 57 | 57 | 58 | 61 | 63 | 65 | 66 | 67 | 68 | 70 | 70 | 72 | 71 | 74 |
| Dec 2007 -12 | 88 | 91 | 91 | 92 | 90 | 85 | 81 | 76 | 68 | 68 | 70 | 69 | 70 | 74 | 76 | 76 | 78 | 79 | 79 | 81 | 82 | 85 | 86 | 87 |

Table1. Mediocre Maximum Relative Humidity Matrix (%) 2007-2012

Khan.S et al [24] narrated that high level of humidity is a major source of latent load and produces substantial chilled water condensate during the cooling and dehumidification process at the cooling coils (evaporators) of air conditioning machines. The authors concluded that $ 27994 per annum can be saved from 3 Towers+Ground+2 Parking+ 7 floors As conferred, the United Arab Emirates experience hot and humid climate and uses air conditioning machines almost all year round. As a result, a considerable amount of condensate water through cooling coils of air conditioning machines is generated. This extensive amount of low temperature condensate water can be harvested through the commercial and residential high rise building's large cooling capacity plant.

This free cooling source of energy can be harvested and utilized in reducing the mechanical plant's capital cost, reducing cooling demand, allowing selection of smaller HVAC equipment, maximizing energy savings, sinking the carbon footprint and increased occupant thermal comfort.

The subsequent approach is discussed to pre cool the condenser entering air by spraying the chilled condensate water. When the fine mist is released into the air, it creates flash evaporation, which sucks heat out of the ambient air and cool it adiabatically which is a recognized scientific principal that has been used for years to lower air temperature in outdoor zones. This cool air when enter in the condenser will improve the condensation and increase the efficiency of the A/C machine.

residential building by reducing the municipal water and utilizing this condensate water.

The aim is to utilize this condensate in the air conditioning application which is typically being wasted to municipal sewerage systems. It is worthwhile and can be utilized.

*Method/Calculations*

High rise buildings in a hot and humid climate use dedicated treated fresh air along with re-circulated air conditioning system. The various states of the United Arab Emirates (UAE) such as Abu Dhabi, Dubai, Sharjah etc., has a large number of high rise buildings. The air-conditioning and ventilation schemes consist of direct expansion (DX) split/package or water cooled recirculated air conditioning units along with treated fresh air handling units are practice for maintaining indoor air quality (IAQ) in the building. The air conditioning system produces significant condensate water during the cooling and dehumidification process.

Aiming on fresh air in discussion here which contributes a significant amount of chilled water condensate during summer and mild seasons.

Typically, Ground+15 floors residential building entail 8100.0 $l.sec^{-1}$($8.10 m^3.sec^{-1}$) as per the subsequent calculation carried out referring ASHRAE Standard 62.1Ventilation rates [25] referred frequently in gulf as shown in Table 2.



| Ground+15 Floors Residential Building | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Bed Room Type** | **Kitchen** | **Bath-1** | **Bath-2** | **Sub Total** | **Qty** | **Total** | **Operation** |
| | **$l.sec^{-1}$** | **$l.sec^{-1}$** | **$l.sec^{-1}$** | **$l.sec^{-1}$** | **Nos.** | **$l.sec^{-1}$** | |
| **2 Bed Room** | 24 | 12 | 12 | 48 | 8 | 384 | Continuous |
| **1 Bed Room** | 24 | 12 | | 36 | 2 | 72 | Continuous |
| **Extract Air /Floor** | | | | | | **456** | |
| **Ground+15 Floors Building's Total Extract Air ; 456 $l.sec^{-1}$ x 16 floors** | | | | | | **7296** | |
| **Ground+15 Floors Building's Total Fresh Air with 10% for pressurization; 7296 $l.sec^{-1}$x 1.10** | | | | | | **8025.60** | |
| **Say** | | | | | | **8100** | |

Table2. Fresh Air and Extract Air Extract Air Management -ASHRAE 62.1

Considering mediocre summer 46.10 $^oC$ (dry bulb) & 29.40 $^oC$ (wet bulb) out door conditions and cooling coil oulet temperatures of 12.77 $^oC$ (dry bulb) &12.22 $^oC$ (wet bulb) which are considered to be ideal for this climate for removing the fresh air latent load effectively during the cooling and dehumidification process.

The total 598.0 kW cooling capacity is required to condition the fresh air as calculated by Psychometric analyzer program [26] as shown in Figure-2. This total cooling capacity is a sum of sensible and latent load. The generation of condensate is function of latent load. Hence the latent capacity of machine 255.0 kW as calculating using (1) that is generating 368.0 $liters.Hr^{-1}$ (1.5 $liters.Hr^{-1}$/ $kW_{latent\ cooling\ capacity}$) is considerable as demonstrated subsequent using (2). This energy is just dumped into sewerage system. It can be used for pre cooling and also avoiding putting more burdens on the sewerage system.

$$L_{\text{cooling capacity}} = 3.0 * Q * (w_{\text{outside air}} - w_{\text{leaving air}}) \quad (1)$$

$$= 255.174 \text{ kW}$$

$$M_{\text{condensate water}} = V * \rho * (w_{\text{outside air}} - w_{\text{leaving air}}) \quad (2)$$

$$= 0.1024 \text{ kg.sec}^{-1}$$
$$= 0.1024 \text{ l.sec}^{-1} = 6.144 \text{ l.min}^{-1} = 368.640 \text{ l.Hr}^{-1}$$

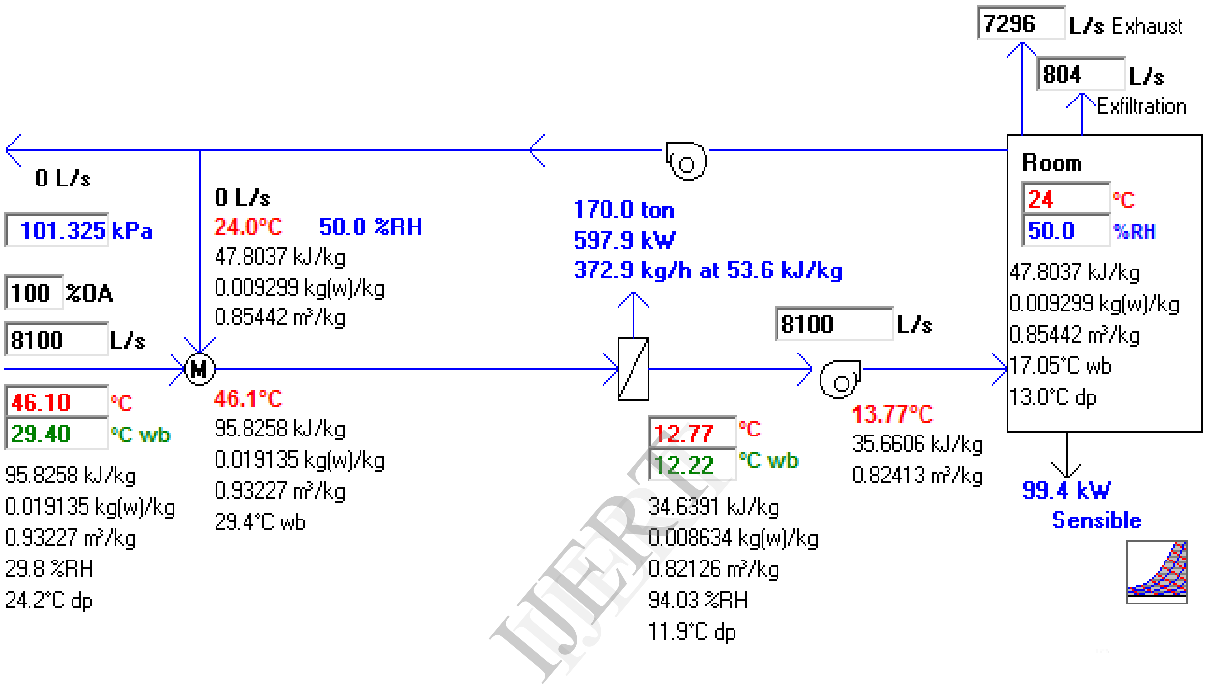


Figure2. Air Psychometric analyzer program

**1. out door conditions**

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 800 | 46.100 | 29.400 | 29.7 | 19.20 | 0.932 | 95.993 | 24.2055 | 1.0720 | 22.6681 | 20.605 |

**2. 10 C bellow evaporative cooling**

| Air Flow (Standard) (L/s) | Dry Bulb (°C) | Wet Bulb (°C) | Relative Humidity (%) | Humidity Ratio (g/kg) | Specific Volume (cu.m/kg) | Enthalpy (kJ/kg) | Dew Point (°C) | Density (kg/cu.m) | Vapor Pressure (mm Hg) | Absolute Humidity (g/cu.m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 800 | 36.100 | 29.293 | 60.8 | 23.25 | 0.908 | 95.993 | 27.3276 | 1.0996 | 27.2761 | 25.598 |

Table3. Air Psychometric data using ASHRAE Psychometric analysis program

## Results

*A/C Units Performance Using Chilled Water Condensate*

The air cooled condenser performance can be enhanced by cooling the entering ambient air by spraying chilled water condensate at constant enthalpy. The fine mist is released into the air near the intake of the condenser which cools the hot ambient air then this air is utilized for cooling condenser to enhance the performance.

The York HTCA30 model; 6.97 kW cooling capacity DX split air cooled unit with 800.0 $\text{l.sec}^{-1}$ (0.80 $\text{m}^3.\text{sec}^{-1}$) condenser fan air volume is selected and pre cooling calculation has furnished at constant enthalpy to ten(10) degree (46.10 $^{\circ}$C to 36.10 $^{\circ}$C) considering air Psychrometry numerals as specified in Table 3.

The amount of 14.25 $l.Hr^{-1}$ chilled water condensate will be required to cool the condenser entering air at constant enthalpy to ten (10) degree bellow as shown through equation (3). The adiabatically pre cooling scheme is illustrated in *Fig.3*.

$$M_{condensate\ water} = V * \rho * (w_{leaving\ air} - w_{outside\ air}) \quad (3)$$

$$= 0.00396\ kg.s^{-1} = 0.00396\ l.sec^{-1} = 0.2376\ l.min^{-1} = 14.256\ l.Hr^{-1}$$

This system comprises pump, mist nozzles, piping arrangement and temperature control. As the tempreature reaches the set point the thermostst will turn on the pump.

The pump activates and condesate water mist is released in the air in front of condensing units.This process drops the temperature of the entering air, which increases the heat exchange at the condenser coil, reduces the head pressure, compressor amperes draw and turn ON the cycle time.

Thus free pre cooling by using condesate improves the performance of the machine and saves energy. The thermostat turns the pump off as the ambient temperature reaches the cut OFF temperature set point. This proces is ilustrated in Fig. *4*.

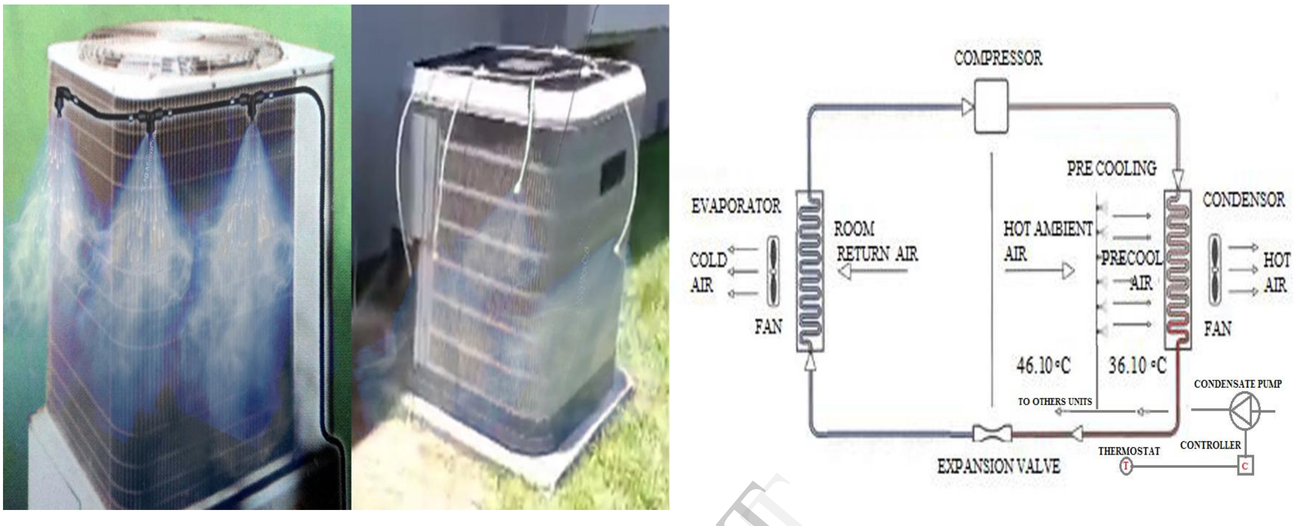




Figure3. Adiabatically pre cooling using condensate water

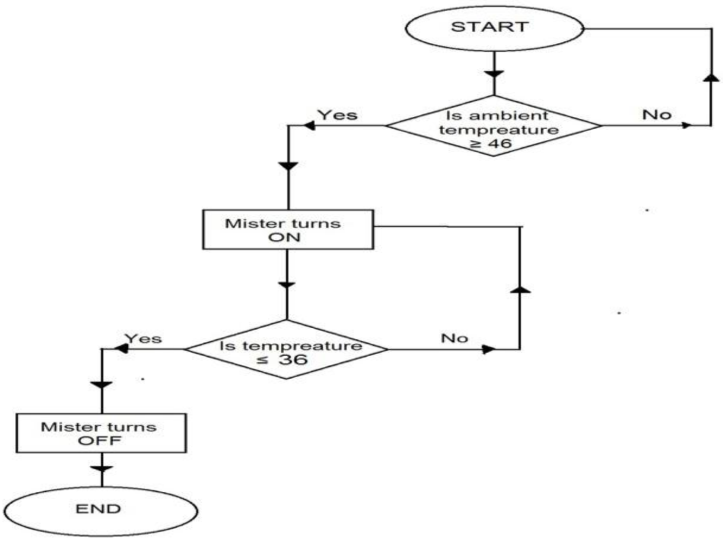


Figure4. Pre cooling process flow chart

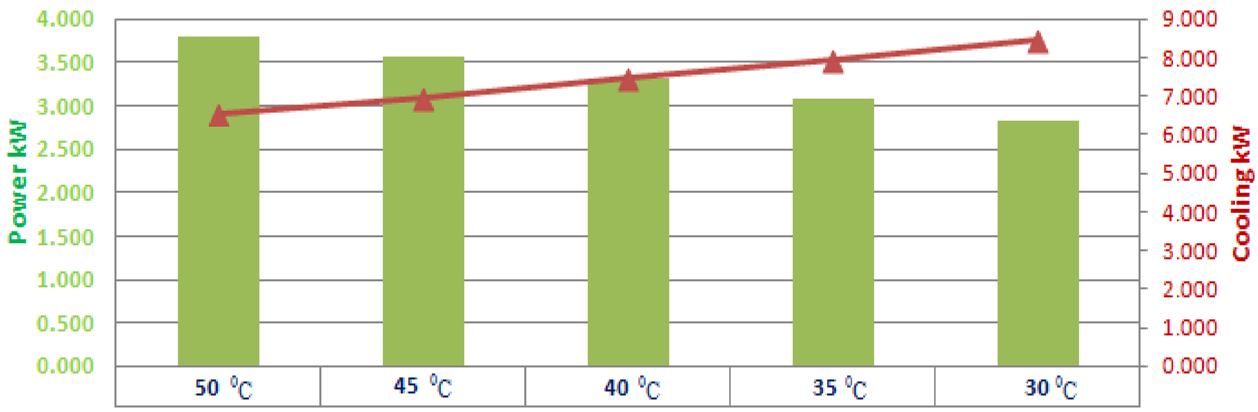


Figure5. Cooling capacity & power input at various condenser entering air temperatures

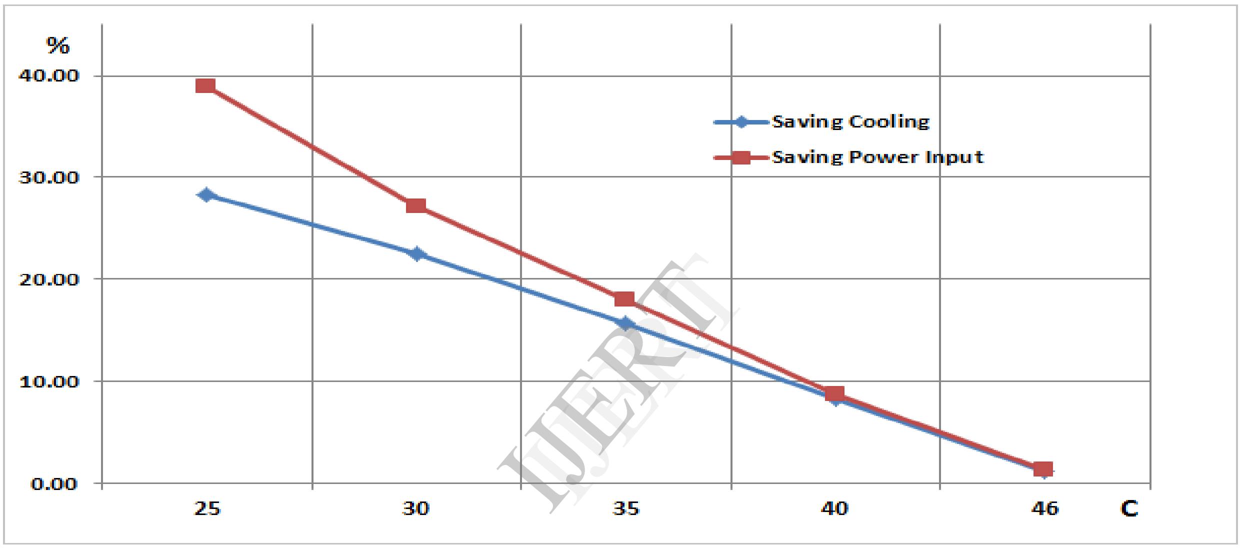


Figure6. Cooling capacity and power input saving (%)

The results shown cooling capacity saving 15.0 per cent (%) ( 1.0 kW) and power input by 18.0 per cent (%) (0.50 kW) can be achived by lowering ten(10) degree air temperature

Conversely, 25 nos. AC units can reduce 3664.17 kg CO2e/month the carbon emission (3.664 Tonnes CO2e/month) at the rate of 0.54284 kg CO2e per kWh emission factor [28] and taking participation in keeping the envoirnment clean.

| Item | Estimated unit rate($) | Qty(Nos.) | Total($) |
|---|---|---|---|
| Mist pump | 400/each | 1.0 | 400 |
| PVC mist nozzles | 1.5/each | 50.0 | 75 |
| PVC pipe | 6.0/meter | 40.0 | 240 |
| Condensate storage tank | 1000.0/each | 1.0 | 1000 |
| Valves, fittings, controls | | | 150 |
| Labor cost | | | 500 |
| **Grand total cost $ (AED)** | | | **2365 (8680)** |

1$=3.67AED Table 4. Estimated cost for condensate water harvesting &distribution

preceding from 46.10 °C to 36.10 °C as illustrated on graphs in *Fig. 5 & 6*.

The estimated cost of infrastructure for 25 nos. A/C machines for chilled water condensate harvesting and distribution for pre cooling will be required as shown in Table 4.

## DISCUSSION

The case study presented,demonstrated that a considerable amount of water, generates through air conditioning machines during cooling and dehumidification process at the cooling coil (evaporator). This condensate can be harvested and employed particularly for pre air cooling at constant enthalpy to improve the performance of the A/C system.

As per electricity rate 23.0 fils (0.23 AED) per kilowatt hour(kWh) for the consumption up to 2,000 kW/month [27] in Dubai; assuming AC unit 'On Cooling Cycling' stays averagely 18 hrs. /day in summer; thus, we can reduce AED 1553/month ($423/month).

There is much saving in not utilizing municipal water. There is a production of 368 l.Hr-1 (97.21 US Gallon.$Hr^{-1}$) condensate water through FAHU. Which provides saving of AED 2100/month($572/month) in summer. Thus total saving AED 3653/month ($995/month) can be attained.

It is reported that annual leakage rate is 12% -20% in unitary split AC system [29] If we reducing the cooling capacity of machine, infect we are reducing the annual leakage rate and emission from the refrigeration system. By reducing merely 0.15 kg /annum leakage of Chlorodifluoromethane (R22), emission can be abridged by 271.50 emission kg Co2e/year (0.2715 tonnes co2e/year) at the rate 1810.0 emission factor-kg $Co_2$e/kg for this freon.

Therefore, this free cooling source can reduce operational cost, mechanical plant's capital cost, allows selection of smaller HVAC equipment and maximize energy savings. The payback period is only less than three (3) months on the initial cost use for this infrastructure as presented in Table 4.

## CONCLUSION

- *The paper demonstrated that considerable amount of water 368.64 l.$Hr^{-1}$ (97.21 US Gallon.$Hr^{-1}$) can be collected through fresh air handling unit (FAHU) and utilized for the pre cooling of associated recirculated air-conditioning units.*
- *The cooling capacity saving 15 per cent (%) and power input by 18 per cent (%) can be achieved by pre cooling the condenser entering air to ten (10) degree bellow and using zero amount of municipal water. More than 25 nos air conditioning units of same capacity can be served.*
- *There are thousands of high and low rise buildings in the UAE and neighboring Gulf countries, the stringent government authorities' polices can implement the proper condensate water harvesting management system to utilize this free energy source in air conditioning application as well as other associated areas to not only save the energy , reducing carbon foot print and operational cost.*
- *The discussion has focused on fresh air handling machine condensate while collection of condensate water from associated recirculated A/C machines can be also carried out and utilize for the same application and pre cooling of additional machines can be achieved.*
- *The results shown are for ten (10) degree reducing the ambient air temperature entering the condenser. The saving can be increased by further lowering the ambient air temperature utilizing condensate water.*

**Variables and Acronyms**

| | | |
|---|---|---|
| *AHU* | *Air Handling Unit* | |
| *ASHRAE* | *American Society of Heating, Refrigerating and Air Conditioning Engineers* | |
| *DEWA* | *Dubai Electricity and Water Authority* | |
| *DXU* | *Direct Expansion Unit* | |
| *DB* | *Dry Bulb Temperature* | *°C* |
| *DP* | *Dew Point* | *°C* |
| *EAD* | *Environment Agency Abu Dhabi* | |
| *ENBG* | *Estidama New Buildings Guidelines Abu Dhabi* | |
| *FAHU* | *Fresh Air Handling Unit* | |
| *FCU* | *Fan Coil Unit* | |
| *HVAC* | *Heating Ventilation and Air-Conditioning* | |
| *kWh* | *Kilowatt hour* | |
| *LEED* | *Leadership in Energy and Environmental Design* | |
| *LPS* | *Liters per Seconds* | |
| $L_{cooling\ capacity}$ | *Latent Cooling Capacity* | *kW, W* |
| *MCS* | *Meter Cube per Seconds* | |
| *Mtoe* | *Metric tonne of oil equivalent* | |
| $M_{condensate\ water}$ | *Mass of condensate water* | $kg.sec^{-1}$ |
| *P* | *Power* | *kW, W* |
| *RH* | *Relative Humidity* | *%* |
| *VAV* | *Variable Air Volume* | |
| *VRF* | *Variable refrigerant flow* | |
| *VSD* | *Variable Speed Drive* | |
| *UAE* | *United Arab Emirates* | |
| *UN* | *United Nations* | |
| *V* | *Volume flow of air* | $m^3.sec^{-1}$, $l.sec^{-1}$ |
| *WB* | *Wet Bulb Temperature* | *°C* |
| *w* | *Specific humidity of air* | $kg/kg^{-1}$ |
| $\rho$ | *Density of air, 1.2041 at 20°C* | $kg.m^{-3}$ |

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