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Energy efficiency for adapted HVAC design approach at hot dry climate zones in Middle East

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Abstract: As the world new trend is to keep the building's design as much as possible meet the green buildings, where the building energy saving is one of the targeted point in the US green buildings. Consultants are looking for the optimization of the electromechanical systems for optimal energy efficient and cost saving operations. On hot dry climate zone, the air conditioning systems represent about 55% to 65 % of the electrical power demands depending on building construction quality and type of application. Designers have to respect the minimum fresh air requirements and the IAQ as specified in local codes based on ASHRAE standard 62.1-2010, accordingly they think about how to reduce the cooling capacity required to accommodating such thermal load as the fresh air thermal load has a significant impact on the sizing of the HVAC system especially in tropic regions for commercial, industrial and in high occupancy applications. Fresh air might utilize dedicated full fresh apparatus and then distribute the pre-cooled outside air to group of re-circulated terminal units instead of individual use of fresh air intakes. While, some applications such as laboratories, hospitals, clean spaces and others, may utilize full fresh air cooling units as direct air conditioning units.

This article focus on the energy savings design concept adopted for the full fresh air handling units especially at hot and dry climate such in Middle East such as Riyadh City in KSA. The concept use indirect and direct evaporative cooling sections packaged with traditional AHU sections.

In hot dry climate zone in US western cities, such as lass Vegas, los angelus, Albuquerque, Tocson, the indirect / direct water evaporation system integrated with the traditional cooling coil is the most energy efficient air cooling system. The publisher technically investigated how far the similar cities located in hot dry climate zone in Middle East could utilize such energy saving benefits. The study is based on the theoretical technical analysis based on the ASHRAE handbook, fundamentals, system and equipments and code of practice referenced to the brand name manufacturer's in this field. The technical analysis study conclude the major annual energy saving that could gained in the full fresh air conditioning units when applied in Riyadh City which might reach to 50 to 65 % comparing to the traditional air conditioning equipment, the saving percentage is varied based on the city exact climate, the IDEC – DEC efficiencies, the requested supply air temperature.

Indeed it is really valuable to the designers to perform such studies in similar climate zones prior selecting of the appropriate air conditioning system in different applications.

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1. Nomenclatures

ASHRAE : American Society of Heating Refrigeration and Air Conditioning
ANSI : American National Standard Institute
AHU : Air Handling Unit
HVAC : Heating Ventilation and Air Conditioning
IAQ : Indoor Air Quality
IDEC : Indirect Evaporative Cooling
DEC : Direct Evaporative Cooling
CC : Cooling Coil
RCC : Regular Cooling Coil
CFM: Cubic Feet Per Minute
FFA: Full Fresh Air
KSA : King Dom Of Saudi Arabia
L/S : Liter Per Second
CFM : Cubic Feet Per Minute
DBT : Dry bulb Temperature

WBT: Wet Bulb Temperature
MCDB: Mean Coincident Dry Bulb Temperature
MCWB: Mean Coincident Wet Bulb Temperature
SF: Supply Fan
DX: Direct Expansion
CHW: Chilled Water
T.Ap. : Temperature Approach

2. Introduction

All the owners are looking forward to minimizing the rate of the electrical power consumptions of the electromechanical systems to avoid the annual cost fee charge of the electricity invoice. The HVAC systems consumed the great part of the electricity in most of application which might reach to 65% of the total electrical power consumption for the overall building electromechanical systems, Accordingly the improvement in the HVAC system design to make the system much more efficient with low power consumption rating shall have a great impact to reduce the expected large amount of the annual operation cost.

Riyadh city in KSA is locating in zone "1-B" hot and dry climate zone as stated in international climate zones by ANSI/ASHRAE/IES Standard 90.1-2010. The common HVAC system is the traditional air conditioning DX-System and chilled water system, however in some buildings application, the evaporative cooling might be applied, but the evaporative cooling couldn't guarantee to achieve the desired space indoor design temperature all over the year, as the operation and the efficiency of the process is directly depending on the outdoor air conditions, which is monthly changed and varied all of the year, so such system is considered as a kind of the environmental improvement regardless the resulting supply air temperature and the indoor conditions.

It will expected that the applying the indirect / direct water evaporation system integrated with the traditional cooling coil in Riyadh city, the HVAC system shall have a great energy efficient air cooling system.
This real application worked and applied in the US –Hot dry Climate cities as described before.

3. Propose System Description

The adapted proposed system is the indirect – direct evaporative cooling combination with cooling coil (DX or ChW).
IDEC: The Indirect evaporative cooling, Figure-1, a secondary (scavenger) air stream is cooled by water. The cooled secondary air stream goes through a heat exchanger, where it cools the primary air stream. The cooled primary air stream is circulated by a blower. Indirect evaporative cooling does not add moisture to the primary air stream as there is no direct contact between the air and the water. Both the dry bulb and wet bulb temperatures are reduced. The heat exchanger is normally stainless steel or polymer tubes, the low air flow velocity through the heat exchanger the high efficiency of the exchanger shall be expected.

DEC: With direct evaporative cooling, Figure-2, outside air is blown through a water-saturated medium (usually cellulose) and cooled by evaporation. The cooled air is circulated by a blower.

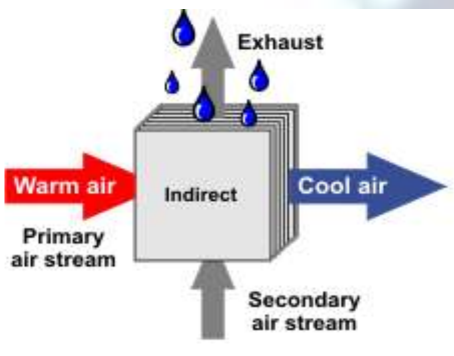

Figure-1

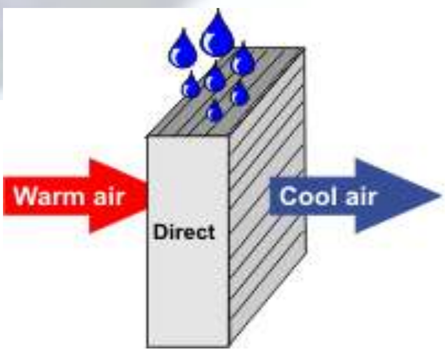

Figure-2

The traditional Dx or CHW air handling units is normally consist of the intake damper, air filters, cooling coil and supply fan. Figure-3. The adapted system is the IDEC-DEC with cooling coil integration system. The same as in figure-4 but with adding combination IDEC-DEC is showing in Figure-4.

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4. System Methodology

The evaluation of energy savings might gained when using both of IDEC and DEC in full fresh air handling unit against the regular full fresh air units, the study will applied to Riyadh city in KSA "Kingdom of Saudi Arabia" that is lies in zone 1-B hot and dry climate zone as stated in international climate zones by ANSI/ASHRAE/IES Standard 90.1-2010 to perform the energy saving technical analysis. Such analysis applied on simple full fresh air space cooling unit with 472.0 l/s (1000 cfm) air flow capacity to brought the outside air cooled to the design supply air temperature 14.00 / 13.50 (DB / WB) consequently.

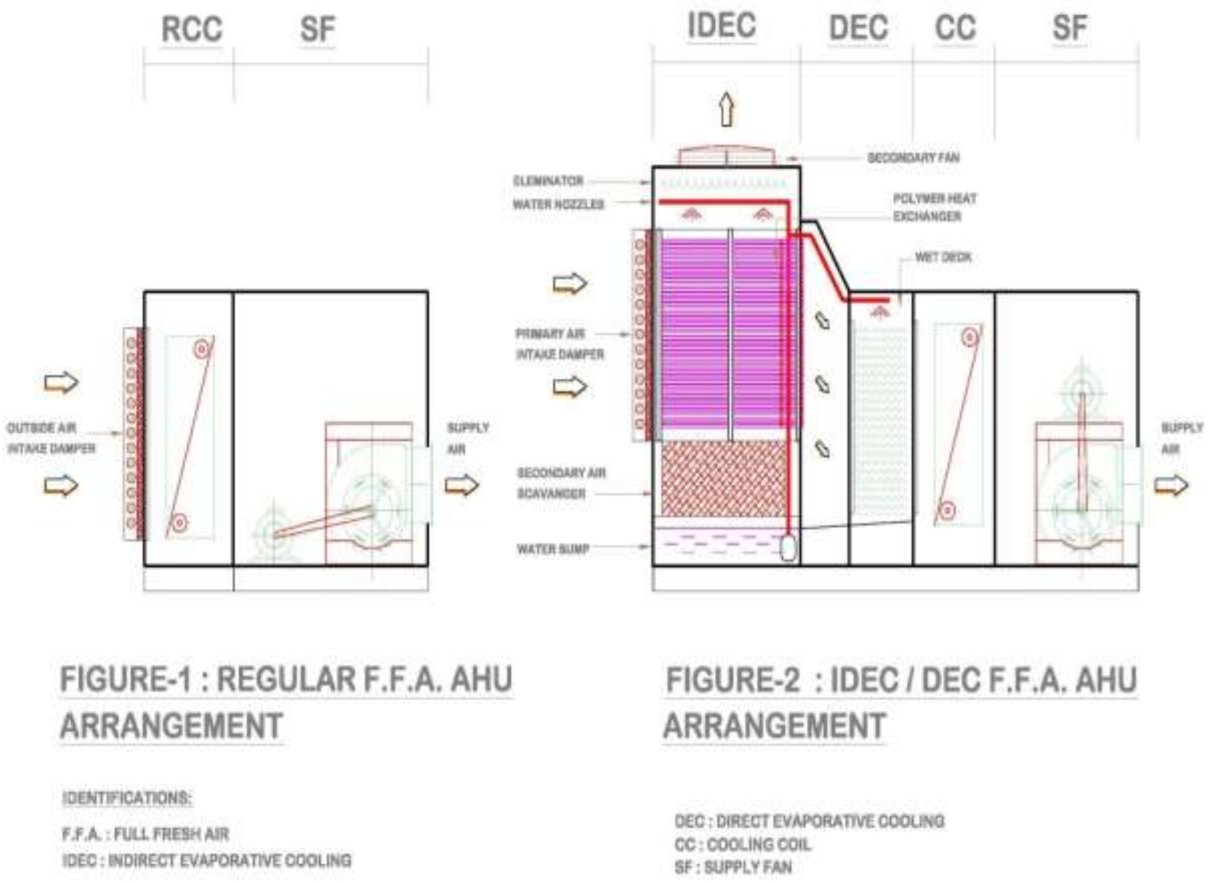

Figure 3 Figure 4

Performed analysis was based on monthly basis in reference to Riyadh ambient conditions specified in the ASHRAE Climate Conditions, where considering two scenarios, first scenario is based on the worst monthly Dry bulb with Mean Coincident Wet Bulb temperature, (DB-MCWB), while the second scenario is based on the worst monthly Wet Bulb with Mean Coincident Dry Bulb temperature, (WB-MCDB). The average results of the two scenarios represent the average cooling load required and reflecting what could be gained when applying the adapted HVAC system. The analysis is considering 60 % polymer heat exchanger efficiency for the IDEC section , while 80 % saturation effectiveness for the DEC section as an average values specified by ASHRAE, Systems & Equipment. Twelve numbers of graphs plotted for scenario-1 and similar graphs for scenario-2, two samples are illustrated in figure 5 & 6, figure 5, Illustrate the cooling process on the Psychometric chart in July at DB-MCWB. While, figure 6, illustrates the cooling process in August at WB-MCDB. Blue lines represent the IDEC-DEC cooling coil plot process, while Orange lines for the regular cooling coil plot process. Figure-5, IDEC-DEC-CC – AHU arrangement process described as the followings:

IDEC: The intake air at (45.8/18.4) sensibly cooled through the IDEC heat exchanger to (29.4/14.4) based on 60% efficiency. (9.5 Kw sensible cooling effect).

DEC: The IDEC leaving air cooled through the DEC in adiabatically cooled process at constant wet bulb temperature to (14.4/12.4) based on 80% saturation effectiveness. (8.7 Kw sensible cooling effect).
C.C: The cooling coil shall cool the DEC leaving air to the design leaving temperature (14.0/12.2). (0.22 Kw sensible cooling effect).

The Regular C.C – AHU arrangement process described as in R.C.C.: The intake air at (45.8/18.4) shall directly cool to the desired leaving condition (14.0/5.4). (18.4 Kw sensible cooling effect).

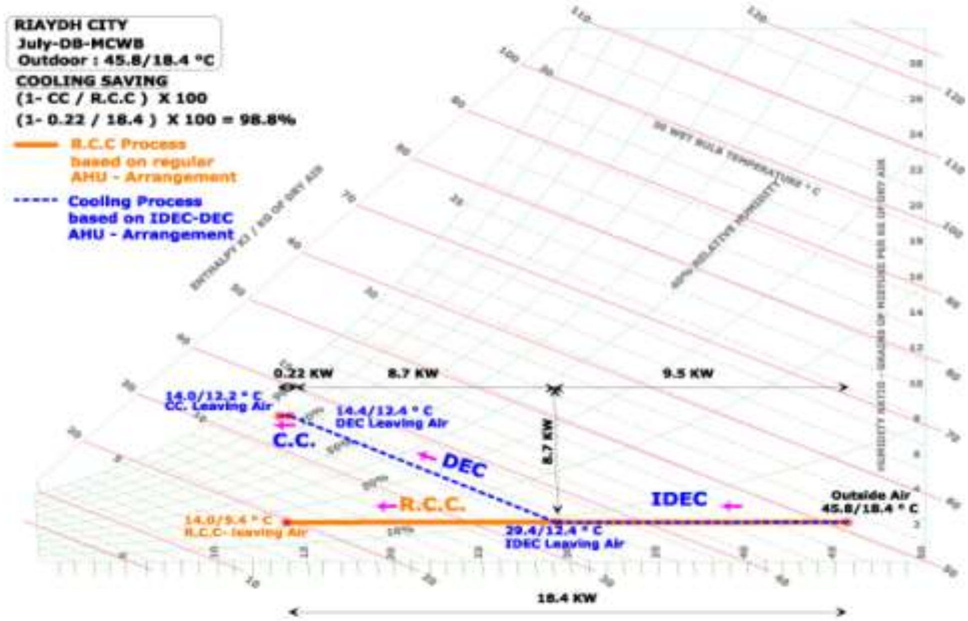

Figure 5: Psychometric chart process plot at July 45.8 / 18.4 (DB / MCWB)

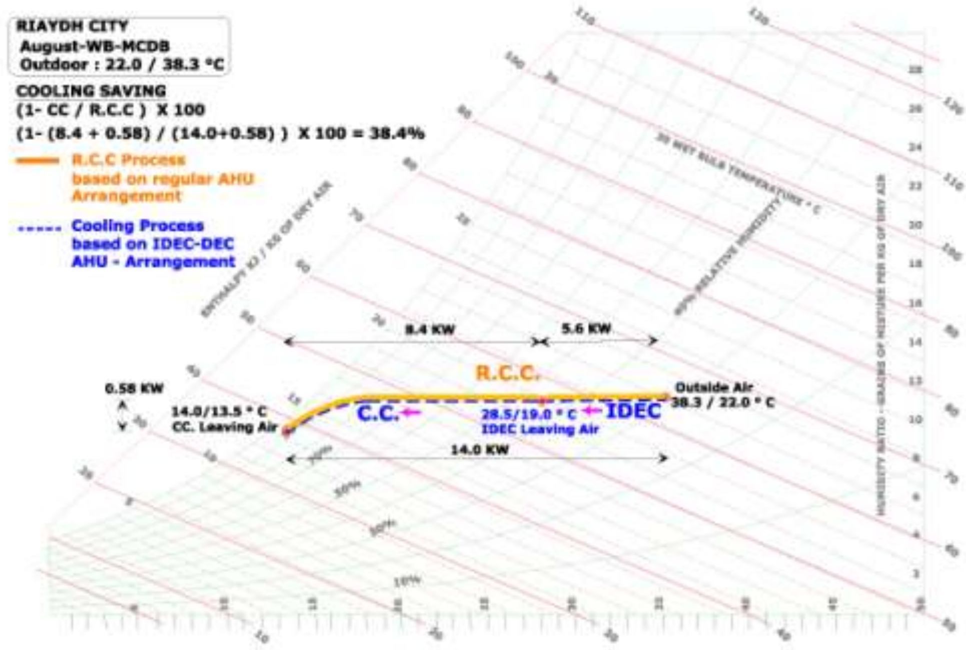

Figure 6 - Psychometric chart process plot at August 22. / 38.3 (WB-MCDB)

In-Figure-6, IDEC-DEC-CC – AHU arrangement process described as the followings:

IDEC: The intake air at (38.2/22.0) sensibly cooled through the IDEC heat exchanger to (28.5/19.0) based on 60% efficiency. (5.6 Kw sensible cooling effect).

DEC: The air passed through the DEC section without operation as the level of the desired humidity ration is lower than the inlet air level. (No cooling effect).

C.C: The cooling coil shall cool and dehumidify the DEC leaving air to the design leaving temperature (14.0/13.5). (8.4 Kw sensible cooling effect).

The Regular C.C – AHU arrangement process described as R.C.C.: The intake air at (38.2/22.0) shall directly cool and dehumidify the air to the desired leaving condition (14.0/13.5). (14.0 Kw sensible cooling effect)

5. System Analyses

The system analysis performed based up on the information of the table-1, the first half of the table is for the scenario-1, the first column identify the month, the second is the dry bulb temperature, the third column is the air off temperature of the IDEC section and the temperature difference between the outdoor and IDEC-off temperatures, the fourth is similarly but for DEC section, the fifth is similarly but for the C.C. the second half of the table is similar but for scenario-2. Let us to identify the T.Ap. as a temperature approach, which reflect the temperature difference between the outdoor and the targeted leaving temperature, the T.Ap. at July (DB-MCWB) shall be 45.8 – 14 = 31.8, accordignlly the IDEC, DEC. CC section shall cater 16.4,15 ,0.4 temperature difference consequently, meaning that 51% , 48% , 1% are the percentage of temperature approach accommodating in the three sections consequently, that simply meaning that the IDEC-DEC sections at the specified outdoor conditions shall accommodate the 99% percentage of the cooling load required.

The annual average percentage considering the two scenarios are 45.9% , 25% , 29.1% for the IDEC, DEC and CC consequently. Simply meaning that 71% of the total sensible cooling load required shall be accommodated through the IDEC-DEC all over the year. This will clearly getting for the table-2 but through the cooling capacities analysis as shown in table-2, The first column identify the month, the second column specifying the regular cooling coil and the cooling coil capacities getting from the plot graph of scenario-1, the third column calculate the cooling saving percentage per each month, the 4th, 5th and 6th columns are similar but based on scenario-2.

The highlighted green values in the table-2 reflect the explained before of the sample graphs,

Table- 1, Average of Temperature Approach Percentage in the two Scenarios

Month	Senario - 1 : DB-MCWB							Senario - 1 : WB-MCDB						
	Out door DB Temp.	IDEC		DEC		C.C.		Out door DB Temp.	IDEC		DEC		C.C.	
		Off Tem	T.Diff	Off Tem	T.Diff	Off Tem	T.Diff		Off Tem	T.Diff	Off Tem	T.Diff	Off Tem	T.Diff
	Deg.C							Deg.C						
January	27.6	19.50	8.10	14.00	5.50	14.00	0.00	22	18.80	3.20	18.8	0.00	14	4.80
Febrauary	30.2	21.00	9.20	14.00	7.00	14.00	0.00	24.4	20.40	4.00	20.4	0.00	14	6.40
March	34.2	23.00	11.20	14.00	9.00	14.00	0.00	26.5	22.00	4.50	22	0.00	14	8.00
April	39.3	26.00	13.30	14.10	11.90	14.00	0.10	29	24.10	4.90	24.1	0.00	14	10.10
May	43.1	28.00	15.10	14.30	13.70	14.00	0.30	35.3	27.20	8.10	27.2	0.00	14	13.20
June	44.8	28.90	15.90	14.50	14.40	14.00	0.50	39	27.80	11.20	22.8	5.00	14	8.80
July	45.8	29.40	16.40	14.40	15.00	14.00	0.40	40.1	28.80	11.30	25.2	3.60	14	11.20
August	45.2	29.80	15.40	15.24	14.56	14.00	1.24	38.3	28.50	9.80	28.5	0.00	14	14.50
September	43.1	28.30	14.80	15.00	13.30	14.00	1.00	35.2	26.50	8.70	26.5	0.00	14	12.50
October	38.9	25.60	13.30	14.00	11.60	14.00	0.00	27.4	23.00	4.40	23	0.00	14	9.00
November	33	22.50	10.50	14.00	8.50	14.00	0.00	25.3	22.00	3.30	22	0.00	14	8.00
December	28.3	20.10	8.20	14.00	6.10	14.00	0.00	22.9	20.00	2.90	20	0.00	14	6.00
Average Temp. Difference			12.62		10.88		0.30			6.36		0.72		9.38
AVG. T.Ap. Perc. / Senario			53.03%		45.73%		1.24%			38.65%		4.36%		56.99%
AVG. T.Ap Perc. / Two Senari			**45.8%**		**25.0%**		**29.1%**							

The cooling Saving: Table-1 conclude that the average annual cooling saving is **71%**, The Average Cooling Rate per month is (145/12) or 12.0 Kw for RCC "Regular Cooling Coil" and 3.56 Kw for IDEC-DEC-CC system, the power consumption shall be 6.24, 1.85 kw consequently where considering 0.52 kw electrical power consumption per KW cooling rate for the DX-System.

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Net Power Savings: By adding 0.2 kw for IDEC-DEC secondary fan power. The Net saving in power consumption shall be (1- (1.85 + 0.2) / 6.24) % or **67%.** The Cost Saving in Power Consumption **2928 SR**, based on 8 working hrs per day and 0.26 SR/Kw Electricity charge rate in KSA.

Cooling Capacity Savings of the installed equipment: The maximum regular cooling capacity at July-DB-MCWB is 18.4 kw, the maximum IDEC-DEC cooling coil capacity shall be at April-WB-MCDB scenario 9.8 KW as extracted from table-1, The IDEC-DEC –cooling coil system shall lead to **48%** reduction of the regular installed cooling capacity.

Table- 2, Average of Monthly Cooling Coil Saving Percentage in the two Scenarios

Month	Senario-1 DB-MCWB		Cooling	Senario-2 WB-MDB		Cooling
	Cooling Coil Capacity		Saving	Cooling Coil Capacity		Saving
	R.C.C.	C.C. IDEC-DEC System	Percent.	R.C.C.	C.C. IDEC-DEC System	Percent.
	Kw		%	Kw		%
January	7.9	0.00	100%	4.8	2.9	39%
February	9.4	0.00	100%	6.7	4.4	34%
March	11.7	0.00	100%	9.2	6.6	28%
April	14.7	0.04	100%	12.5	9.8	22%
May	16.9	0.17	99%	14.3	9.6	33%
June	17.8	0.27	98%	14.5	5.0	65%
July	18.4	0.22	99%	15.1	6.5	57%
August	18.1	0.72	96%	14.58	8.89	39%
September	17.0	0.59	96%	12.3	7.3	41%
October	14.5	0.00	100%	11.0	8.5	23%
November	11.0	0.00	100%	10.5	8.6	18%
December	8.3	0.00	100%	7.4	5.7	22%
Annual Cool. Saving	165.7	2.0	**99%**	132.9	83.8	**37%**
Average Of Annual Cool.ing Saving	149.3	42.8	**71%**			

6. System Water Efficiency

Make up water due to the Water Evaporation: Through the IDEC – DEC sections, there is heat transfer by water evaporation, result in lost of the amount of the water circulation, table-3, evaluate the water evaporation rates in monthly basis for the two scenarios.
The water evaporation consumption per each month is specified in the same manner explained in the cooling coil capacities explained in table-1.

Table- 3 , Average of the Monthly Water Evaporation in two scenarios

Month	Senario-1, DB-MWB				Senario-2, WB-MCDB			
	Out Door Wet Bulb Temperature - C	DB-MWB Water Evaporation		Monthly Total	Out Door Wet Bulb Temperature - C	WB-MCDB Water Evaporation		Monthly Total
		IDEC-Sec.	DEC-Sec.	IDEC-DEC		IDEC-Sec.	DEC-Sec.	IDEC-DEC
		L/Hr		L/Hr		L/Hr		L/Hr
January	14.2	8.97	5.62	14.58	16.6	3.63	0.00	3.63
Febrauary	14.9	10.19	6.59	16.78	17.7	4.49	0.00	4.49
March	15.6	12.31	8.32	20.63	19.1	4.94	0.00	4.94
April	17.1	14.57	10.03	24.60	20.9	5.38	0.00	5.38
May	17.9	16.43	11.50	27.94	21.8	8.88	0.00	8.88
June	18.3	17.23	12.12	29.35	20.4	12.18	4.19	16.37
July	18.4	17.79	12.58	30.38	21.2	12.35	2.89	15.24
August	19.4	16.75	12.16	28.91	22	10.67	0.00	10.67
September	18.4	16.10	11.12	27.23	20.8	9.48	0.00	9.48
October	16.8	14.51	10.04	24.55	20.1	4.86	0.00	4.86
November	15.5	11.60	7.72	19.33	19.8	3.67	0.00	3.67
December	14.6	9.15	5.74	14.89	18.1	3.22	0.00	3.22
Average Water evap. / month /senario				23.26				7.57
Average Water evap./ month / two senarios				15.42				

The average water evaporation / month for two scenarios shall be 15.42 l/hr. considering 10 % bleeding rate *(2008 ASHRAE Handbook—HVAC Systems and Equipment Evaporative Air Cooling Equipment),* the makeup water shall be 16.96 l/hr. The running cost of the water evaporation per year (SR) shall be **183 SR**, where considering 4 SR/m3 of water consumption charge rate of KSA –Government.

Net of Running Cost Savings: Subtract the cost of the water evaporation from the cost savings of the electrical power consumption, the net system operation running savings shall be **2745 SR /Year per 472 L/S supply air (1000CFM).**

7. System Evaluation

Technical notifications extracted from table-1 and 2, The IDEC – DEC sections could cater significant part of the process cooling from the cooling coil capacity required and reach to 100% of the desired cooling in some cases, thus no need of the cooling coil, this is depending up on the outdoor conditions.

The IDEC-DEC sections couldn't able to achieve the design supply air temperature in all scenarios without utilizing supplement cooling from the cooling coil section even it will be minor step cooling.

Benefits of the IDEC – DEC packaged unit integrated to the regular DX or chilled water system:

Substantial energy and cost savings
Improve the system EER “Energy Efficiency Ratio” and Reduced peak power demand
Improved indoor air quality
Life cycle cost effectiveness
Easily integrated into built-up systems
Wide variety of packages available
Provide humidification and dehumidification when needed
Easy to use with direct digital control (DDC)
Reduced pollution emissions
Minimizing the chlorofluorocarbon (CFC) usage.

8. Summary & Conclusion

The IDEC-DEC –Cooling coil system for full fresh air applications has major cooling saving reach to 71% comparing with the traditional full fresh air units in hot dry climate zones. The saving in the Electrical power consumption shall expect to be 67% comparing with the regular system. 48% of the installed cooling capacity shall be saved in case of using the IDEC-DEC cooling coil packaged units. There is a cost saving in both of the initial and running cost when utilizing the adapted IDEC-DEC – Cooling coil system.

The system is not only applied in the hot – dry climate, it is valuable, the designers to investigate and make similar analysis in semi-hot dry climate, it might gain some benefits but with less saving impact.
The IDEC – DEC air handling unit is bigger size than the regular AHU units and required almost double foot print space.
The IDEC-DEC capacity selection should be sized at the worst outdoor wet bulb temperature as specified in the ANSI/ASHRAE/IES Standard 90.1-2010. Evaporative coolers do not provide suitable growth conditions for the bacteria and generally do not release an aerosol. A good maintenance program eliminates potential microbial problems and reduces the concern for disease transmittal (ASHRAE 1998, 2000; Puckorius et al. 1995).

The designers has to investigate the project local market to find out the suppliers of such proposed system as it has no wide range of manufacturer's in middle east employed with, the import products available in US manufacturer’s such as Munter's, Energy LAB and Speck air.

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