# Energy Saving Potential of Indirect Evaporative Cooling as Fresh Air Pre-cooling in Different Climatic Conditions in Saudi Arabia.

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## ABSTRACT

*This study evaluates the energy savings potential of indirect evaporative cooling (IEC) as fresh air pre-cooling in hot climatic conditions in Saudi Arabia. For this purpose, a commercial IEC unit was pilot-tested in a building located in Ras Tanura refinery. The IEC unit effectiveness and water consumption were monitored and verified against published performance data. Energy saving calculation method for hybrid IEC/DX-based AC system was performed and a generalized energy saving chart was generated for various simulated climatic conditions using Ras Tanura building example. Depending on the climatic conditions observed, results show that fresh air pre-cooling using IEC has an energy savings range from 10% to 70% when compared to using DX-based AC system alone. Results are consistent with literature information and should be of a great value to enable HVAC designers evaluate quickly the energy savings potential when applying IEC as fresh air pre-cooling.*

## INTRODUCTION

Neglecting building indoor air quality while pursuing other energy efficiency goals, such as tighter building envelops, can result in building environments that negatively impact the health, comfort and productivity of occupants (sick building syndrome) and therefore defeat the overall goal of building design, including reduced costs. Smoking areas, schools, labs, hospitals and positive pressure buildings will need even higher attention due to their higher ventilation rates requirements. Fresh air ventilation using a dedicated mechanical outdoor air system became a very important component for modern HVAC system design. The HVAC designer must therefore implement creative solutions to meet both conflicting requirements in an optimum manner.

Saudi Aramco, the national oil company of Saudi Arabia and the sole energy provider to the kingdom, is committed to explore energy efficient alternative technologies to reduce the overall electrical energy consumption and its peak demand. One of the areas that Saudi Aramco has embarked on is fresh air pre-cooling using IEC technology. Evaporative cooling is an environmentally friendly and energy efficient method for cooling buildings in hot and dry regions. Except for few regions, Saudi Arabia climate is characterized by extreme hot temperatures during the summer with elevated humidity levels on the eastern and western provinces which demands a variety of cooling systems designs to optimize energy consumption, reduce harmful emissions, and provide the badly needed summer comfort conditions. Given the size of Saudi Aramco, there are literally tens of millions of cubic feet per minute (CFM) of fresh air within all existing building types which offer a great opportunity not only to apply IEC to conserve energy and reduce harmful emissions, but also to lead the Kingdom by example and promote this technology Kingdom-wide. For this purpose, a pilot project was started to explore the possibility of deploying IEC system to precool the fresh air before it enters a building in Ras Tanura refinery. The following section provides a general overview of evaporative cooling from fresh air pre-cooling application point of view.

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## DIRECT EVAPORATIVE COOLING (DEC)

DEC is the simplest form of evaporative air conditioning, which is widely applied in dry regions such as the city of Riyadh, Saudi Arabia. This system typically uses a fan to draw hot outdoor air into a building through a porous wetted medium. The water absorbs heat as it evaporates from the porous wetting medium, and the air thus leaves the DEC at a lower temperature. Air dry bulb temperature reduces as it is moistened in this adiabatic (constant enthalpy) saturation process. Being a constant enthalpy process, DEC system cannot be used for fresh air-precooling as it will have no positive impact on reducing building overall air-conditioning load. Figures 1 depicts DEC psychrometrically and figure 2 depicts DEC conceptually.

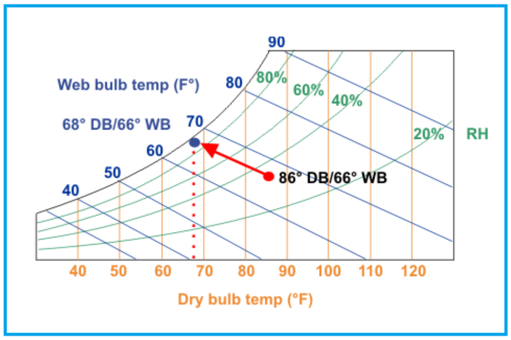



Figure 1. Adiabatic process of DEC

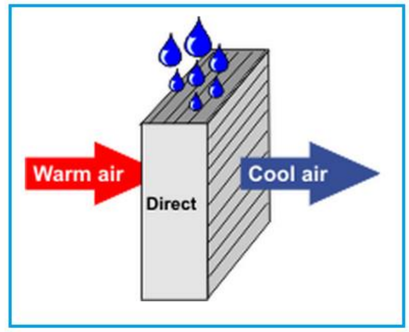



Figure 2. DEC concept

## INDIRECT EVAPORATIVE COOLING (IDE)

Indirect evaporative cooling (IEC) uses a wet surface heat exchanger where a non-adiabatic evaporation takes place. Two streams of air are used; primary air is cooled in dry passages which is separated from wet passages where secondary air and water flow. Evaporation occurs in wet passages and heat is removed from primary air through impermeable separating wall and evaporates water into the secondary air. Contrary to DEC, IEC can be used for fresh air pre-cooling as it provides sensible cooling and hence will have positive impact on reducing building overall air-conditioning load. Figure 3 depicts IEC psychrometrically and figure 4 depicts IEC conceptually.

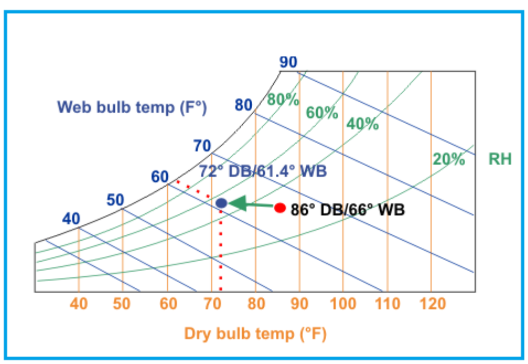



Figure 3. Adiabatic process of IEC

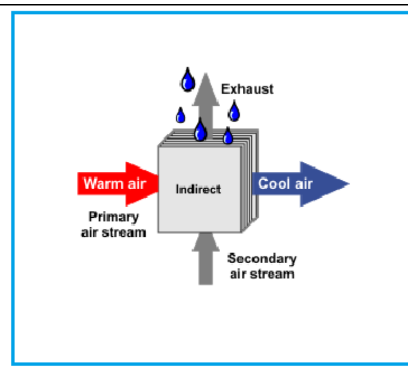



Figure 4. Indirect evaporative cooler

Given the special nature of evaporative cooling as being climate-dependent, it was necessary to review literature from various countries and understand how IEC was applied for fresh-air precooling. The authors' extensive literature reviews revealed that this subject has been so far treated mainly from the research aspects to enhance the heat and mass transfer to apply IEC/DEC and/or IEC as fresh air pre-cooling in various climatic conditions of a specific country (for example, Iran, China, Korea and Kuwait). These previous works also provided excellent information on

IEC energy saving performance in conjunction DX-based HVAC system (1, 2, 3, 4, 5). The authors established that these previous works, however, did not offer HVAC designers a quick and easy tool to determine the energy savings for inlet air pre-cooling in all climatic conditions. It is the authors hope that the results of this study will provide HVAC design community with a tool to evaluate quickly the potential percentage energy savings when applying fresh air pre-cooling using IEC.

## PILOT FIELD TESTING

A commercial IEC field test unit was installed in a 1000 square feet (100 square meters) building to provide fresh air pre-cooling at Ras Tanura refinery. The unit uses a heat rejecter very similar in its operation to a cooling tower however it is designed to achieve much lower wet bulb approach. Due to its large top surface area and low water flow, the water in the heat rejecter is cooled by evaporation by the working air stream. The cold water (1F higher than the outdoor wet bulb temperature) is pumped to the indirect heat exchanger (water coil) while the primary air stream cool down by passing over the heat exchanger. Figure 5 depicts the IEC unit with its internal main componentry and table 1 shows the main specifications of the IEC unit (6). It should be noted that the unit effectiveness is the only performance rating provided by the manufacturer as there are currently no industry program for rating the cooling capacity of the IEC products.

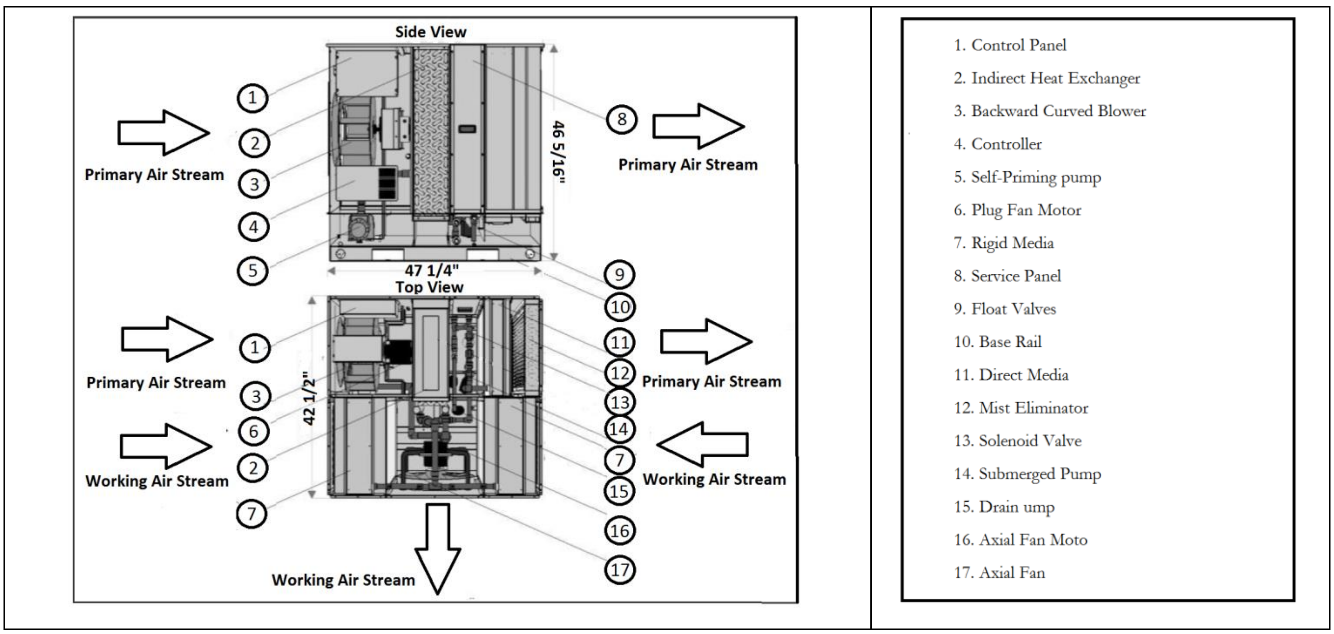



Figure 5. IEC pilot-test unit and main components

Table 1. IEC pilot-test unit specification

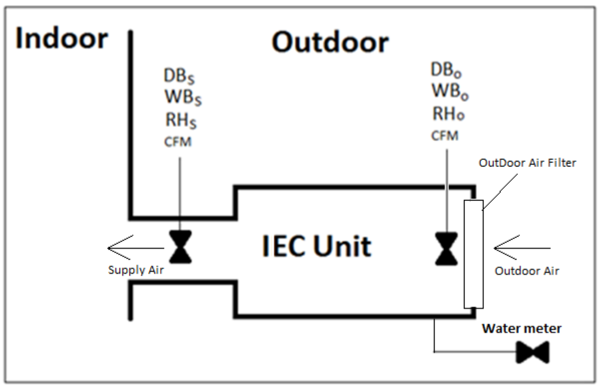
| | |
|---|---|
| **Dimensions (LXWXH)** | 49 X 44 X 46 ½ inches |
| **Weight Operating / Dry** | 900 lbs./500 lbs. |
| **Blower** | 1.5HP, Centrifugal plug fan direct drive 18", single speed |
| **Indirect Pump** | Self-priming 1.5HP for water supply of heat exchanger |
| **Drain Pump** | Submerged 240VAC 1Ph/60Hz |
| **Max Power** | 2000 Watt |
| **Secondary Fan** | 0.5 HP, Axial 18" |
| **Heat Rejecter Media** | Rigid cooling media |
| **Media Depth** | 2” X 12” |
| **Indirect Heat Exchanger** | Tube and fin water coil |

| | |
|---|---|
| **Indirect Heat Exchanger Filter** | Tube and fin water Coil 2", pleated washable filter |
| **Effectiveness** | 80% |

The pilot study objectives were determined as follows:

1. Evaluate the technical viability of deploying IEC to precool the fresh air in hot and humid conditions and verify the effectiveness of the IEC unit.
2. Develop energy savings chart be used by HVAC designers for similar installations and in different climatic conditions across Saudi Arabia.

After commissioning the IEC unit, all variables parameters shown in figure 6 were measured and recorded hourly using a data logger. Water consumption was also metered to evaluate overall water usage in each operating mode and also capture the water power consumption. Figure 6 shows the location of measurement points along with all measured variables.




| | |
|---|---|
| **$DB_O$** | Outdoor Dry Bulb(F) |
| **$WB_O$** | Outdoor Wet Bulb (F) |
| **$RH_O$** | Outdoor Relative Humidity (%) |
| **$DB_S$** | Supply Dry Bulb(F) |
| **$WB_S$** | Supply Wet Bulb (F) |
| **$RH_S$** | Supply Relative Humidity (%) |
| **Water Meter** | Water Consumption GPH |
| **CFM** | Air Flow in CFM |

Figure 6. Measurement locations and measured variables

To reduce the number of the data points collected, the hourly readings were averaged every 24 hours and an average daily value for each variable was provided by the data logger. Table 2 shows sample snapshot of four consecutive averaged daily readings from the data logger for all measured variables (numbers were rounded to the nearest full digit due to table formatting constraints). Figure 7 depicts the four readings of the IEC unit operation psychrometrically. The unit cooling capacity (Q) and the energy efficiency ratio (EER) were calculated based on the formula provided below. The rating test procedure outlined in (7) was extended to calculate the EER. It should be noted that the total unit electrical power in the EER calculations included the electrical power used for the water used to run the IEC unit. The water consumption has been converted to electrical power using the information provided in (8). The IEC unit design allows no direct contact between the water and the supply air streams and hence grey water or treated recycled water could have been used instead of the more expensive desalinated water.

$Q = \Delta h * CFM * 4.45$ (Btu/h)
EER= Cooling capacity (Btu/h)/ Total unit electrical power (Watt),

Table 2. Measured variables and snapshot test readings.

| OD DB (F) | OD RH (%) | OD WB (F) | OD Enthalpy Btu/1b. | Supply DB (F) | Supply RH (%) | Supply WB (F) | Supply Enthalpy Btu/Lb. | CFM | Power KW | Capacity KBTU | EER | Water Consumption GPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 91 | 49% | 75 | 39 | 76 | 75% | 70 | 34 | 2202 | 1.825 | 44 | **24** | **7.1** |
| 92 | 47% | 76 | 39 | 77 | 73% | 70 | 34 | 2205 | 1.837 | 49 | **26** | **8.2** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **93** | **47%** | **77** | **40** | **78** | **73%** | **71** | **35** | **2207** | 1.925 | **48** | **25** | **7.9** |
| **91** | **49%** | **75** | **39** | **76** | **74%** | **70** | **34** | **2201** | 1.853 | **46** | **25** | **7.0** |

The effectiveness of the IEC units is defined by the following equation:

$$\text{Effectiveness} = \frac{(\text{Dry Bulb}_{\text{Outdoor}} - \text{Dry Bulb}_{\text{Supply}})}{(\text{Dry Bulb}_{\text{Outdoor}} - \text{Wet Bulb}_{\text{Outdoor}})}$$

The effectiveness of the IEC unit for the test period was calculated and table 3 shows sample snapshot of the values for those operating points depicted in figure 7. While the unit absolute cooling capacity and corresponding EER are weather-dependent and vary by the variation of the wet bulb depression (dry bulb-wet bulb), however, the wet bulb effectiveness can be considered constant. It should be noted that the published nameplate effectiveness of the IEC unit as per the manufacturer was 80%, which is lower than the observed effectiveness range from the pilot test. Calculating higher effectiveness could be attributed to variations in manufacturing tolerances and oversizing some of the IEC components. This finding is also consistent with similar test results from our literature reviews (9).

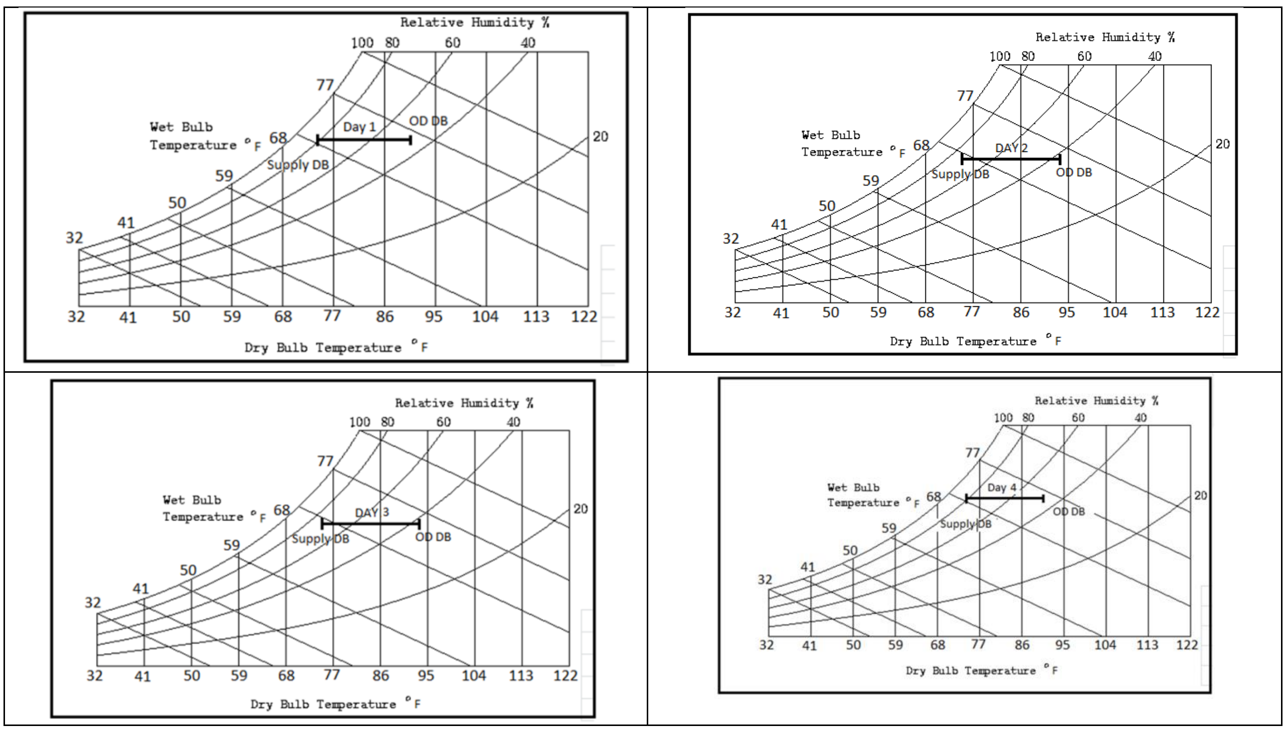



Figure 7. Selected test operating points for the IEC unit

Table 3. IEC unit effectiveness

| Day | OD DB (F) | OD WB (F) | Supply DB (F) | Effectiveness |
|---|---|---|---|---|
| 1 | 90.8 | 75.4 | 76.2 | 95% |
| 2 | 92.2 | 75.9 | 76.7 | 95% |
| 3 | 92.9 | 76.6 | 77.7 | 93% |
| 4 | 90.7 | 75.4 | 76.1 | 95% |

The next step was to determine energy saving potential of IEC as a fresh air pre-cooling in multiple climates and generate a family of energy savings curves. The following example explains the approach and method used.

A 4900 square feet (460 square meters) office building, located in Ras Tanura, has a total internal load of 25 TOR (Tons of Refrigeration) and is served by a DX-based AC unit which has an EER of 11. The building fresh air requirement is 2500 CFM. Summer room design condition is 78 F dry bulb and 50% RH, which gives an enthalpy of 30 Btu/lb. According to ASHRAE fundamentals Handbook, Ras Tanura has a 0.4% dry bulb design temperature of 105.8 F, and a coincident wet bulb temperature of 80.6 F, which gives an enthalpy of 44 Btu/lb. The IEC unit ultimate task is to bring the outside fresh air condition as close as possible to the room air condition in order to minimize the impact of fresh air load on the DX-based AC unit. To find the IEC cooling capacity to accomplish this task :

$Q = \Delta h * CFM * 4.45$

$\Delta h = (h_{outdoor} - h_{indoor)}$ = (44 - 30) = 14 Btu/Ib.

Q= 14 X 2500 X 4.45= 155,750 BTU ≈ 13 TOR

The supply air temperature of the IEC unit is calculated using the effectiveness equation. In order to be conservative with the savings calculations, the lower effectiveness of 80% declared by the unit manufacturer was used, instead of the higher one observed during the test.

Supply air temperature = 105.8F- (105.8F-80.6F) X 0.80= 85.6F

Since the IEC process is pure sensible cooling, the primary air dew point temperature is constant before and after the IEC unit. At 105.8 F dry bulb and 80.6 F wet bulb, the dew point temperature is 71.8 F. Knowing that the supply air dry bulb temperature is 85.6F and the dew point is 71.8 F, the supply wet bulb temperature and the enthalpy can be obtained by plotting this point on the Psychrometric chart. The supply wet bulb temperature and the enthalpy is found to be 75.3 F and 38.7 Btu/Ib. respectively. The cooling capacity of the IEC unit can be determined as follows:

$\Delta h = (h_{outdoor} - h_{Supply\,)}$ = (44 - 38.7) = 5.3 Btu/Ib.

Q=5.3 X 2500X 4.45= 59,000 BTU/Ib. ≈ 4.9 TOR.

This means that the remaining 8.1 TOR (13 - 4.9) will be handled by the DX-based AC unit. In order to be conservative with the energy saving calculations, the unit nameplate power of 2000 watts will be used instead of the slightly lower power observed from the pilot test. The IEC unit EER in this case will be 59000/2000= 29.5

The EER of the hybrid IEC/DX system is the weighted average of IEC and DX as per the equation.

$$EER_{Hybrid} = \frac{(EER_{IEC} \times Q_{IEC}) + (EER_{DX} \times Q_{DX})}{Q_{Total}}$$

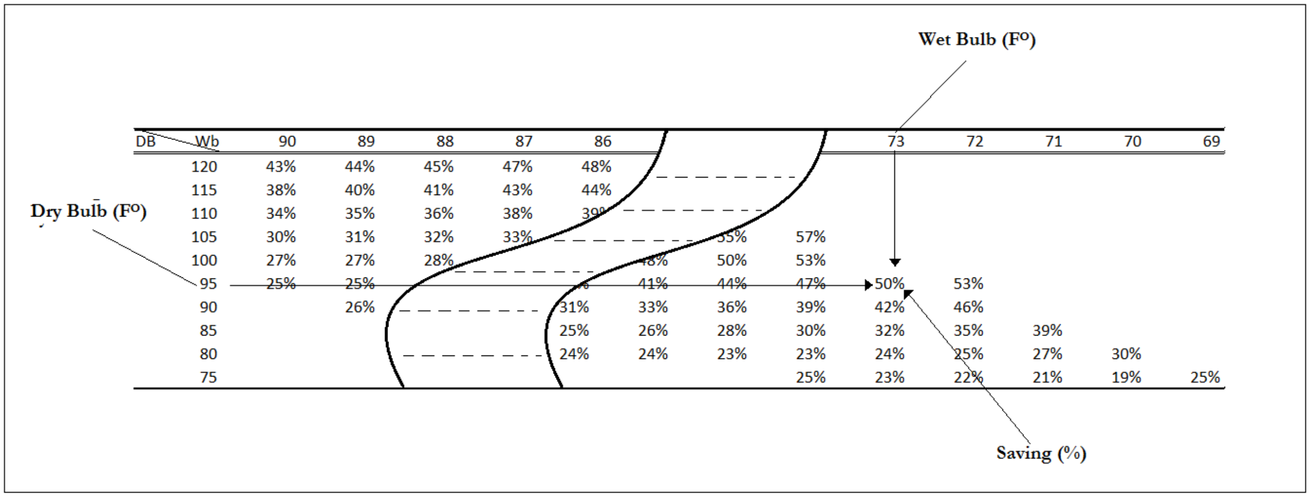
= ((29.5 * 4.9) + (11 * 8.1))/13 = 17.7

To determine the savaging of using the hybrid operation IEC/DX as opposed to using DX-based AC only:

Saving $= 1 - \frac{EER_{DX}}{EER_{Hybrid}}$ =1-(11/17.7) = 38%

Using the same energy savings calculation method, we construed an energy savings table for a range of dry bulb temperatures and wet bulb temperatures from 120 F to 75F and from 90 F to 69F respectively. Although the original table has 1F interval for both the dry bulb and wet bulb temperature, for brevity purpose, table 4, shows a reduced version of the original table with 5F and 1F interval for the dry bulb and wet bulb temperatures respectively. Table 4 shows also an example of the powerful benefit of determining the percentage energy saving of deploying IEC for fresh air pre-cooling as opposed to using DX only, for a given dry bulb and wet bulb temperatures. It should be noted that this table is specific to an installation deploying IEC unit with 80% effectiveness and a DX unit and EER of 11.

Table 4. IEC energy saving in fresh air pre-cooling application




## DISCUSSION

Table 4 provides IEC energy savings percentages based on specific conditions of a hybrid IDE/DX, namely 80% effectiveness and 11 EER. The same calculations method can be followed for different effectiveness and EER values and similar table can be produced. However, knowing that 80% effectiveness and 11 EER are the most commonly encountered performance values for IEC and DX products respectively, Table 4 still can be used to give the designer a quick ball park figure, with a high degree of confidence, as of what is the expected energy savings for a hybrid IEC/DX fresh air pre-cooling application as opposed to using DX-based AC unit alone. This confidence is further supported by the fact that the rated EER of the DX unit was assumed constant in the calculation; however, it is known that the EER of DX-based AC system has inverse relationship with outdoor dry bulb temperature. DX product manufacturers provide HVAC designers with EER reduction tables for elevated outdoor temperature (10). This is contrary to the energy performance of IEC unit which has direct relationship with elevated outdoor temperature. Therefore, IEC offers, in addition to the aforementioned energy savings potentials, an opportunity for electrical peak demand shaving.

Given the fact that many HVAC designers prefer to work with sizing charts, table 4 was used to generate an energy savings chart as shown in figure 8. By inspecting this energy saving chart, it is interesting to observe a combination of a straight and curved lines for wet bulb temperature. The straight lines represent the IEC/DX hybrid operation and the curved lines represent the IEC operation only when the outdoor wet bulb temperature is low enough to allow IEC to be sufficient to carry the entire cooling load required for fresh air pre-cooling. Our development of performance curves for IEC units is consistent with the ASHRAE standard for rating IEC products (11), which confirms that the cooling capacity calculations shall be presented as performance curves. Figure 8 shows and example how to utilize this chart is to obtain an approximate saving that could be achieved from using such technology in the city of Jizan Saudi Arabia. Jizan summer design temperatures are 113F dry bulb and 83 wet bulb and by plotting these 2 points on the chart, the energy savaging will be around 45%.

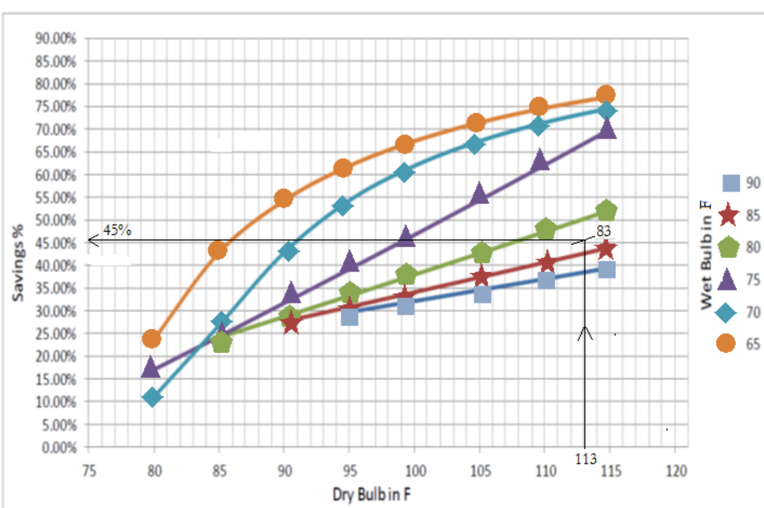


Figure 8. IEC energy saving in fresh air pre-cooling application

## CONCLUSION

Fresh air pre-cooling using indirect evaporative cooling (IEC) offers a great energy saving and emission reduction opportunities. In a pilot test at one of Ras Tanura buildings, the effectiveness and energy performance of a commercial indirect evaporative cooling (IEC) unit were monitored and evaluated. An energy saving calculation method for fresh air pre-cooling using a hybrid IEC/DX system was presented and subsequently further expanded to cover a wide range of simulated climatic conditions. Energy savings chart developed in this study will provide HVAC designers with a tool to evaluate quickly the potential percentage energy savings when applying fresh air pre-cooling using IEC as opposed to using DX-based system alone, which is estimated to be between 10% and 70%.


## ACKNOWLEDGMENTS

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