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# A STUDY ON AIR-COOLED CHILLERS WITH EVAPORATIVELY COOLED CONDENSER FOR 3 TYPES OF CLIMATE

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**Abstract**: This paper presents a performance analysis of air-cooled chillers with evaporatively cooled condenser in 3 different cities of Turkey with the help of meteorological data provided from the Turkish State Meteorological Service (TSMS). The aim of the study is to determine the effects of evaporative cooling on inlet air of the condenser unit under various humidity and temperature conditions, and therefore on cooling performance (COP) of the air conditioning system. Considering the summer season between June and September for 4 months, it is assumed that the cooling requirements are provided by the direct expansion air-conditioners and the condenser inlet air is cooled by evaporative cooler with 70% effectiveness. The results show that after the evaporative cooling the highest COP increase of the chillers is occurred in most arid city as 40.5%, while the lowest increase was in the most humid city as 15.5%. This improvement increased the cooling capacity by 14.3% and 5.56%, correspondingly. In addition, the mean electrical consumption is considerably decreased as 9.97%, 15.49% and 6.97% for 3 different cities. The highest water consumption was around 5 tons per day for 10 hours of operation and 1400 $m^3$/min mean air flow rate.
**Keywords**: Air-cooled chiller, climate, condenser, COP, evaporative cooling, water consumption

# EVAPORATİF SOĞUTULAN KONDENSERE SAHİP HAVA SOĞUTMALI SOĞUTMA GRUBUNUN 3 İKLİM TİPİ İÇİN İNCELENMESİ

**Özet**: Bu makalede, evaporatif olarak soğutulan kondensere sahip hava soğutmalı bir soğutma grubunun performans analizi, Türkiye'deki 3 ayrı şehir için Türkiye Cumhuriyeti Meteoroloji Genel Müdürlüğü'nden (MGM) alınan veriler yardımıyla gerçekleştirilmiştir. Çalışmanın amacı, evaporatif soğutmanın kondenser giriş havası ve dolayısıyla da sistemin soğutma performansı (COP) üzerine etkisini çeşitli nem ve sıcaklık şartları için incelemektir. Haziran ve Eylül ayları arasındaki 4 aylık yaz sezonu için, soğutma ihtiyacının direkt genleşmeli klima cihazlarıyla sağlandığı ve kondenser giriş havasının 70% etkenliğe sahip bir evaporatif soğutma grubu ile soğutulduğu kabul edilmiştir. Elde edilen sonuçlara göre evaporatif soğutmadan sonra soğutma grubundaki en yüksek COP artışı 40,5% değeri ile en kurak iklime sahip olan şehirde, en düşük artış ise 15,5% değeri ile en nemli şehirde gerçekleşmiştir. Bu iyileşme benzer şekilde soğutma kapasitesini ise en kurak iklimde 14,3% ve en nemli iklimde 5,56% oranında arttırmıştır. Bu duruma ek olarak, ortalama elektrik tüketimi 3 farklı şehir için 9,97%, 15,49% ve 6,97% olmak üzere önemli ölçüde düşmüştür. En yüksek su tüketimi, 10 saatlik çalışma süresi ve 1400 $m^3$/dk ortalama hava debisi için günde yaklaşık 5 tondur.
**Anahtar Kelimeler**: Hava soğutmalı soğutma grubu, iklim, kondenser, COP, evaporatif soğutma, su tüketimi

## NOMENCLATURE

| | |
|---|---|
| $\dot{m}_w$ | Water flow rate [kg/h] |
| $\dot{m}_a$ | Air flow rate [kg/h] |
| $T_{in}$ | Condenser inlet air temperature [°C] |
| $T_1$ | Inlet dry bulb temperature [°C] |
| $T_2$ | Outlet dry bulb temperature [°C] |
| $T_{2x}$ | Outlet wet bulb temperature [°C] |
| $w_1$ | Specific humidity of inlet air [g/kg] |
| $w_2$ | Specific humidity of outlet air [g/kg] |
| $w_{2x}$ | Specific humidity at wet bulb temperature [g/kg] |

*Greek Symbols*

| | |
|---|---|
| ε | Effectiveness $\left[{w_1 - w_2}/{w_1 - w_{2x}}\right]$ |
| $\phi$ | Relative humidity [%] |

*Abbreviations*

| | |
|---|---|
| AEC | After Evaporative Cooling |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BEC | Before Evaporative Cooling |
| COP | Coefficient of Performance |
| TSMS | Turkish State Meteorological Service |

## INTRODUCTION

Air-cooled chillers are available in depending on user's needs and requests, hence due to this flexibility, they are commonly used in commercial buildings. They are much cheaper, easier to install and maintain compared to water cooled or ground source systems. On the other hand, their COP is worse than their competitors which is quite a bit of disadvantage (Camargo *et al.*, 2005). Therefore, researchers who are interested in air-cooled air conditioners are looking for ways to increase their performance. The cooling performance of air-cooled systems highly depends on ambient air conditions. It is widely known that, the performance of the system decreases when the inlet air temperature increases. This effect especially occurs in summer when the ambient air temperature is high and the cooling load is at its peak value. In order to decrease the inlet air temperature, evaporative cooling can be used. During the evaporative cooling process, cooling is done by adiabatic humidification of air. For this reason, the air passing through evaporative cooler needs to be hot and dry for an effective evaporative cooling (Camargo *et al.*, 2005). Thus, it is not suitable for every climate and a performance evaluation considering the climate of the area is usually recommended before installation of the system.

Wang et al. (2014) experimentally investigated the increase in COP of an air conditioning system by utilizing an evaporative cooling condenser. Their experimental results support the fact that there is an inverse relation between the condenser inlet dry bulb temperature and the COP. Increase of COP in the range from 6.1% to 18% was measured depending on mass flow rate of refrigerant that went into the evaporator. Therefore there was a 14.3% power reduction on the compressor. The researchers also reported that the cost-optimal dry bulb temperature for this system to be applied is 33.1°C. Yang et al. (2012) reported an alternative system for evaporative coolers to pre-cool the air before entering to the condenser. Their study is based on the effect of water mist system on the energy efficiency of air cooled chillers under various operating conditions. They have reported that under the conventional head pressure control (HPC) with a designed water mist generation rate, the COP is increased up to 21.3% while under variable condensing temperature control (CTC), chiller COP increased by up to 51.5% with optimal water mist generation rate. The study was performed in subtropical climate for CTC coupling with optimal water mist generation rate and as a result, the annual total electricity consumption for cooling was reduced by 14.1%.

Energy saving potential of an indirect evaporative cooler (IEC) is evaluated with an analytical study by Maheshwari et al. (2001). Using the performance results of IEC units and meteorological data of two different locations in Kuwait, the cooling capacity is determined to be 3.1 and 2.4 tons of refrigeration. Yu and Chan (2006; 2011) performed two different analysis to determine the improvement of COP. On their first study, a new condenser design using evaporative pre-coolers and variable speed fans is proposed. The results of the first study showed that, with an adjustment on the condenser fan operation and wet bulb temperature of outdoor air, the COP can be maximized and a 5.6 – 113.4% increase can be achieved. On their second study, researchers tried to lower the dry bulb temperature of outdoor air via mist pre-cooling and investigate the system with simulation. The simulation demonstrated that, with an optimal mist control and drawing on the manufacturer and operating data, the electrical consumption decreased around 18%.

Sarntichartsak and Thepa (2013) performed the modeling and experimental analysis of an inverter air conditioner with evaporatively cooled condenser. The change in frequency, water flow rate and spraying temperature are tested for their effects on the COP. The results revealed that the highest COP can be achieved with water injection rate of 200 l/h for low frequency and 100 l/h at high frequency. In addition, the researchers concluded that the models they proposed in the study are in agreement with the test data. Hajidavalloo (2007) also searched for possible ways to increase the performance of a window air-conditioner, especially for very hot ambient air temperatures (about 50 °C) where these devices are commonly used to cool homes. In order to cool down the air before it enters to the condenser, two cooling pads are installed to the both sides of air conditioner and water is injected in them. The experimental results showed a considerable amount of improvement on thermodynamic characteristics, 16% decrease on power consumption and 55% increase on COP. Hwang et al. (2001) compared the performance of an innovative evaporatively cooled condenser with a conventional air-cooled condenser for a split heat pump system. Their experimental results revealed that the evaporatively cooled condenser has a higher capacity than the air-cooled condenser by 1.8 to 8.1%, a higher COP by 11.1 to 21.6% and higher seasonal energy efficiency ratio by 14.5%.

As can be seen from the previous work available in the literature, increasing the performance of air-cooled systems by using evaporative cooling is highly attractive field of study among the researchers. The general approach on almost all of these studies is to apply various operating conditions to a single system in one region. However, the evaporative cooling performance is highly depend on ambient air conditions. It is more applicable when the air is hot and dry (Camargo *et al.*, 2005). Therefore the climate of the area is an important parameter.

In order to investigate the effects of climate on the evaporative cooling and therefore on cooling performance (COP) of the air conditioning system, 3 different cities in Turkey representing 3 types of specific climate conditions are compared. This theoretical analysis is accomplished by the data provided by TSMS and the chiller unit specifications are retrieved from the commercially available unit catalogues. The parametric study will also involve the calculation of electrical consumption along with the amount of water consumption during the evaporative cooling process which is not mentioned on the previous studies and assumed to be quite important by the authors of the present study.

## EVAPORATIVE COOLING

Evaporative cooling uses the basic thermodynamic concept of evaporation to cool the air and is one of the first known cooling systems in history. Although, they weren't much preferred in time due to the developments in air conditioning systems. Lately, because of low electrical consumption and more fresh air production compared to vapor compression systems, they started to take more attention.

In an evaporative cooler, either a pump circulates the water from a reservoir and sprays it on to a cooling pad or special materials are used as pads to soak water. These special pads are able to hold the water for a long time and have high air permeability. After the pads are wet enough, a fan draws air from outside the unit through the moistened pad. As the ambient air passes through the pad, the air is cooled by the evaporation. The only mechanical parts of the system are the fan and circulation pump which makes the system much simpler. A schematic diagram of a basic evaporative cooler can be seen in Fig. 1.

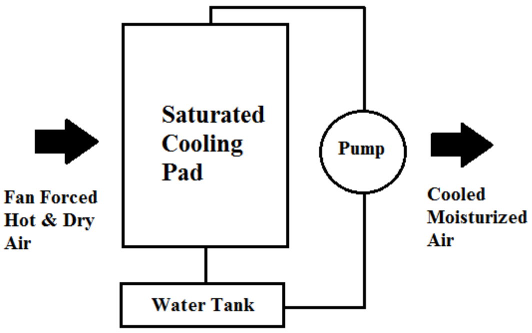


**Figure 1.** Schematic diagram of a basic evaporative cooler.

This type of evaporative cooling where the process air contacts directly with water is called direct evaporative cooling (Hao *et al.*, 2013). Other known types of evaporative cooling are indirect and semi-indirect systems. It should be kept in mind that, while using a wet system like evaporative cooler, some health problems might occur if the system is not maintained properly. The risk is usually Legionella or algae growth, hence the maintenance needs more attention while working with evaporative coolers.

Evaporative coolers can be well combined with air-cooled chillers to decrease the inlet air temperature of condenser. Evaporative cooling is simple and economical way for cooling the inlet air since it does not require any mechanical refrigeration and consumes little power by fan and pump (Hao *et al.*, 2013). Therefore combining these two systems is an energy efficient method.

## CASE STUDY

A theoretical analysis is performed by using the meteorological data of the TSMS for 3 different cities in Turkey, representing the 3 different types of climate conditions. Considering the summer season between June and September for 4 months, it is assumed that the cooling requirements are provided by the direct expansion air-conditioners. The aim of the study is to determine the effects of evaporative cooling on inlet air of the condenser unit under various humidity and temperature conditions, and therefore on COP of the air conditioning system. It is acknowledged by the researchers that the key to COP enhancement is to reduce the average surrounding air temperature (Wang *et al.*, 2014), and evaporative cooling just seems to be perfect for the job because it is already using the surrounding air for cooling and is also known as 'natural cooling'.

### Managing the Meteorological Data

The meteorological data for the summer period (i.e. June, July, August and September) of 4 years (between 2010 and 2013) is obtained from TSMS. The raw data had temperature and humidity values for 24 hours of each day. Since the operation period of cooling units are considered between 7:00 am and 5:00 pm, any values apart from this range is removed from calculations. Additionally, due to the global warming, greenhouse gases and environmental damage, humidity and temperature values are changing annually. Thus, to achieve the most accurate humidity and temperature values, the data retrieved from TSMS is subjected to further calculations and average values of temperature and humidity are calculated for each operating hour of the summer period.

### Climate Properties

In this study, 3 cities of Turkey; Ankara, Şanlıurfa and Antalya that represent 3 zones are considered. Turkey has a unique climate where one can experience different seasonal properties at the same time. Even on the same season, the ambient air conditions can change significantly. Considering the summer season, the humidity and temperature levels of different cities during the day and on the average is completely different than one another. Therefore, 3 cities which represent 3 climate classes are chosen and compared to determine the cooling performance of the system. Climate classifications of the cities is determined according to the classification methods used for ASHRAE Standards and is given in Table 1 (Esiyok, 2006). In addition, cities will be named as I, II and III for the rest of the article as mentioned in Table 1.

**Table 1.** Climate classifications of the cities (Esiyok, 2006).

| *Notation* | *City* | *Class* | *Description* |
|---|---|---|---|
| *I* | Ankara | 4A | Mixed – Humid |
| *II* | Şanlıurfa | 3B | Warm – Dry |
| *III* | Antalya | 3A | Warm – Humid |

**Thermodynamic Calculations**

As it is known, cooling is done by adiabatic humidification of air during the evaporative cooling process. When dry and hot air passes through a wet surface, the water evaporates, the required energy for evaporation is lost from the air, thus reducing its temperature. Two types of temperature is important when dealing with evaporative cooling systems; dry bulb and wet bulb. Dry bulb is the air temperature measured by a regular thermometer while wet bulb describes the temperature indicated by a moistened thermometer bulb exposed to the air flow. The adiabatic humidification process occurs on the wet bulb temperature line of inlet air on the psychrometric chart (Fig. 2). If the water temperature is almost same as the air temperature, the enthalpy can be assumed constant. Therefore during the evaporative cooling, relative and specific humidity of air increases. As can be seen from Fig. 2, the highest point in the process is marked as '2x' which is the saturated state of air (100% relative humidity). Although in practice, it is impossible to reach that point. Usually the process ends around 10-30% lower than 100% relative humidity. It depends on the efficiency of the evaporative cooler and is called 'effectiveness'. In this study, the calculations were performed for 70% effectiveness. The equation to determine the value allows calculating properties of outlet air. The corresponding equation is as follows;

$$\varepsilon = \frac{1-2\ line}{1-2x\ line} = \frac{T_1 - T_2}{T_1 - T_{2x}} = \frac{w_1 - w_2}{w_1 - w_{2x}} \quad (1)$$

where, $T_1$ is inlet and $T_2$ is outlet dry bulb temperature, $T_{2x}$ is outlet wet bulb temperature and w is specific humidity value of corresponding points.

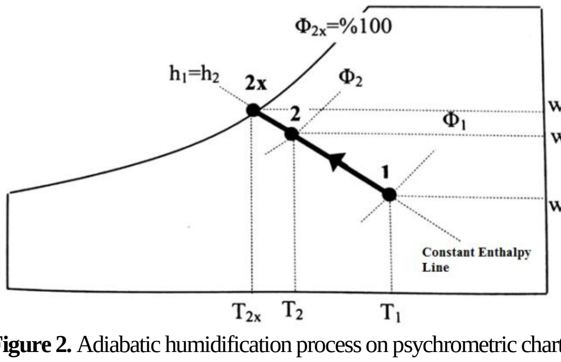


**Figure 2.** Adiabatic humidification process on psychrometric chart.

**Performance Evaluation of the System**

The theoretical performance analysis of a cooling system operating 10 hours a day between 07:00 and 17:00 is performed for 3 different cities and 4 months during the summer season. It is assumed that the inlet air of the condenser unit of air-cooled chillers is evaporatively cooled. Depending on the inlet air conditions that the evaporative cooler is provided, the outlet air conditions in terms of temperature and humidity is changed, and as a result the COP, cooling capacity and electrical consumption is affected.

First of all, in order to make a performance analysis on air-conditioners, the properties of 15 various types of (labeled device A to O) commercially available air conditioners are gathered from the producing companies. Afterwards, each air-conditioner is analyzed individually in terms of cooling capacity, power consumption and COP at the same temperature range (20°C and 50 °C). An example of the analysis is given in both Table 2 and Fig. 3 for device A.

It is clear from the Fig. 3 that increasing the inlet temperature to condenser decreases both cooling capacity and the COP. The mean values are gathered from the individual analysis for 15 devices, and given in Table 3 along with the additional information of the devices evaluated in this study.

**Table 2.** An example of detailed properties of an air conditioner (Device A).

| *Temperature [°C]* | *Cooling Capacity [kW]* | *Power Consumption [kW]* | *COP* |
|---|---|---|---|
| *20* | 295 | 72.7 | 4.06 |
| *25* | 282 | 79.1 | 3.57 |
| *30* | 269 | 86.2 | 3.12 |
| *35* | 254 | 94 | 2.70 |
| *40* | 237 | 103 | 2.30 |
| *43* | 227 | 108 | 2.10 |

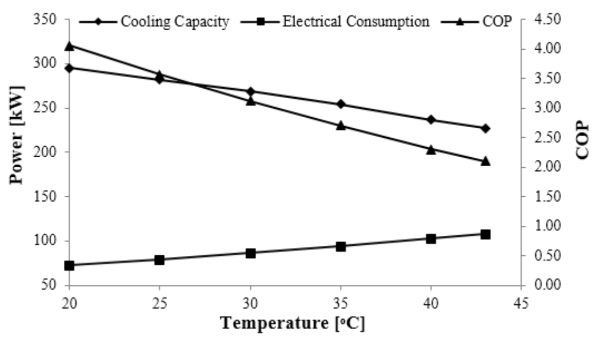


**Figure 3.** Adiabatic humidification process on psychrometric chart.

From the available information in the catalogues, the COP regime of the air-conditioners is also determined for inlet temperature between 20°C and 50°C. In order to accomplish that, the air-conditioners are compared in terms of COP for the same operating temperature range and given in a single graph (Fig. 4). From the corresponding graph, a polynomial equation is formed with a regression analysis ($R^2$ =0.9909) to determine the relationship between COP and inlet air temperature. The equation is as follows;

$$COP = 0.0013\, T_{in}^{\ 2} - 0.1664\, T_{in} + 7.1605$$
$$20°C < T_{in} < 50°C \quad (2)$$

**Table 3.** The mean properties of the air-conditioners between 20°C and 50°C.

| | *Cooling Capacity [kW]* | *Refrigerant* | *Air Flow Rate [m³/min]* | *COP* | *Properties of the air-conditioner* |
|---|---|---|---|---|---|
| *A* | 261 | R-410A | 1600 | 2.97 | Low noise |
| *B* | 277 | R-410A | 1573 | 3.20 | High efficiency, standard noise |
| *C* | 272 | R-410A | 1362 | 3.11 | High efficiency, low noise |
| *D* | 242 | R-410A | 1269 | 2.60 | Standard efficiency and noise |
| *E* | 240 | R-410A | 1269 | 3.07 | High efficiency, standard noise |
| *F* | 231 | R-410A | 1400 | 3.00 | High efficiency,low noise |
| *G* | 259 | R-410A | 1400 | 2.98 | Standard efficiency |
| *H* | 275 | R-134a | 1404 | 3.08 | Standard efficiency |
| *I* | 289 | R-134a | 1620 | 3.27 | High efficiency |
| *J* | 277 | R-134a | 1404 | 2.99 | Standard efficiency, low noise |
| *K* | 300 | R-134a | 1620 | 3.43 | High efficiency, low noise |
| *L* | 252 | R-134a | 1404 | 2.57 | Standard efficiency, low noise |
| *M* | 296 | R-134a | 1620 | 3.31 | High efficiency,low noise |
| *N* | 276 | R-134a | 1404 | 2.98 | Standard efficiency, high static pressure |
| *O* | 249 | R-134a | 1291 | 2.75 | Standard efficiency |

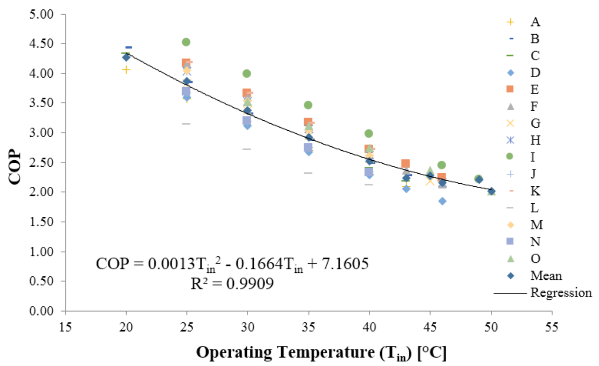


**Figure 4.** The COP regime of the air-conditioners.

By using the same technique, the change in cooling capacity is also determined and another polynomial equation is formed. The corresponding graph can be seen in Fig. 5 and the equation is also given in Eq. 3;

$$Cooling\ Cap. = 0.0051{T_{in}}^2 - 3.5485T_{in} + 380.11 \quad 20°C < T_{in} < 50°C \qquad (3)$$

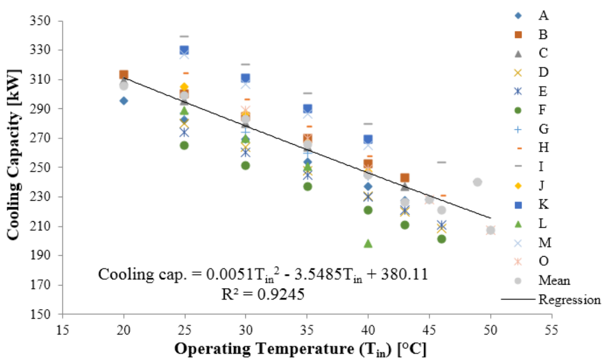


**Figure 5.** The cooling capacity regime of the air-conditioners.

The aim of forming temperature depended equations for COP and cooling capacity regimes is to determine the amount of increase on the corresponding values after evaporative cooling (AEC) of the inlet air. With this method, the performance is analyzed for a system operating 10 hours a day between 7:00 am and 5:00 pm in 3 different cities and 4 months during the summer season. The results are given in results and discussion section.

The decrease in electrical consumption of air-conditioning units is also considered as a part of performance analysis. The electrical consumption both before and after evaporative cooling is calculated and the results are compared. The following equation is used for determining the amount of consumption;

$$\text{Electrical consumption} = {\text{Cooling Capacity}}/{COP} \qquad (4)$$

The most important point while doing evaporative cooling is not to forget the nature of the cooling process which uses the latent heat of evaporation. Hence, there is a constant need of water supply to air which sometimes results in high amount of water consumption depending on the capacity. In other words, it should be kept in mind that while benefiting from COP and electrical consumption, the loss because of water consumption needs to be considered. Therefore, the amount of water consumption under several operating conditions within the scope of this study is also calculated. Eq. 5 is used to perform this analysis;

$$\dot{m}_w = \dot{m}_a(w_2 - w_1) \qquad (5)$$

## RESULTS AND DISCUSSION

According to the methodology given in previous section, the results will be presented respectively in this section. First of all, the meteorological data is managed in order to determine the inlet air properties before the evaporative cooling (BEC). According to the mean temperature and humidity values that are calculated for each month for individual city, the temperature order was almost always II>III>I from highest to lowest while the humidity order was III>I>II. This is the natural result of the typical climate properties of the cities which is previously mentioned in Table 1.

The temperature and humidity regime of the corresponding cities for August is given as an example in Fig. 6 and Fig. 7, respectively. It can be seen from Fig. 6 that, the daily mean temperature of city III does not change significantly and highest temperature difference occurs in city I.

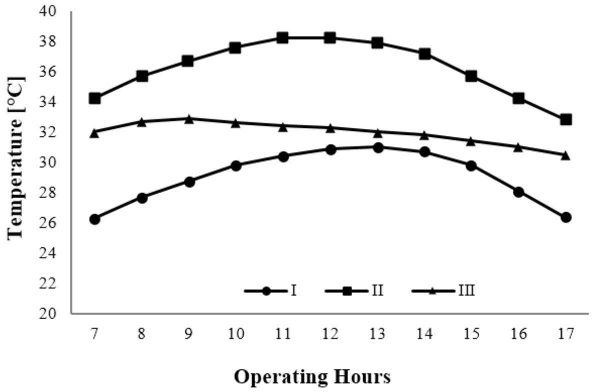


**Figure 6.** The temperature regime of the cities for August.

Fig. 7 shows that there is a decrease in humidity in cities I and II by noon then a slight increase occurs while it is constantly high and keeps increasing in city III. It has been found out in previous studies that the increase in COP could be more significant if the chillers operate in hot and arid regions where the relative humidity is predominantly below 50% (Yu and Chan, 2011). In our case, according to both Fig. 6 and Fig. 7 it can be said that the evaporative cooling is most applicable in city II, since it has the highest temperature and lowest relative humidity compared to other two. City I also has low humidity but its temperature range is low while city III has notably high temperature range but also have the highest relative humidity. All these climate properties of the cities and their effects on COP will be further given.

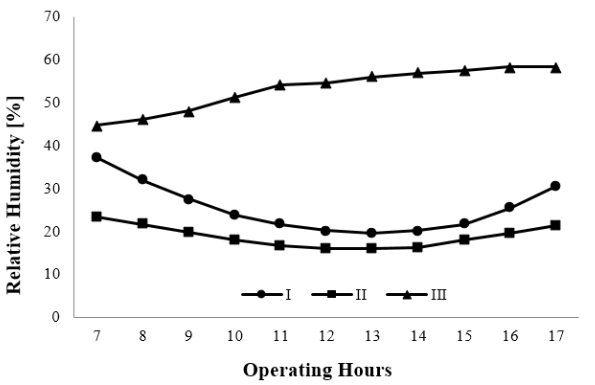


**Figure 7.** The humidity regime of the cities for August.

Evaporative cooling is performed for the entire summer season and the performance analysis is carried out accordingly. The amount of air temperature decreased by evaporative cooling is depended only on the climate properties of the cities, because the effectiveness of the evaporative cooler considered constant as 70%. In order to demonstrate the differences between 3 cities, the results for August are given for each city.

In city I, which is classified as mixed and humid, evaporative cooling was able to lower the air temperature around 9°C. As can be seen from Fig. 8, at some hours the inlet air of the condenser even drops below 20°C. If the evaporative cooler have been designed for direct cooling, these temperature levels and humidity of outlet air would be unsuitable for thermal comfort. However, air will enter the condenser, which means lower temperature values can provide better performance. This statement is also supported with the results of the study because the highest mean COP after evaporative cooling is occurred in city I and calculated as 4.32.

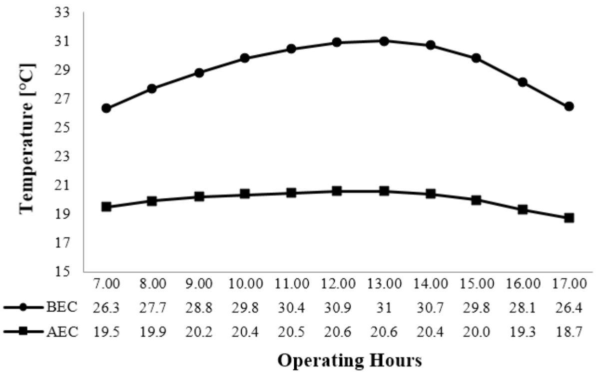


**Figure 8.** Temperature regime of city I before and after evaporative cooling in August.

In Fig. 9, the temperature difference of city II is given. The results show that the most effective evaporative cooling occurs in this city with 13°C drop in temperature. It is aforementioned that this city is warm and dry therefore most favorable by evaporative cooling. According to these results, it also expected that the most COP increase will be occurred in this city as well.

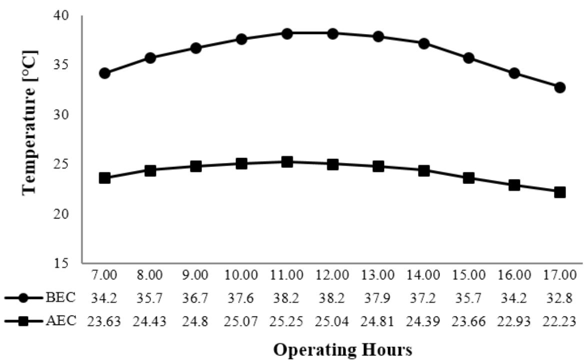


**Figure 9.** Temperature regime of city II before and after evaporative cooling in August.

The daily mean temperature is quite high and the change is very minor in city III (Fig. 10). But the evaporative cooler can not operate effectively above

50% relative humidity. Therefore, the mean temperature decrease is only occurred as 4-5°C.

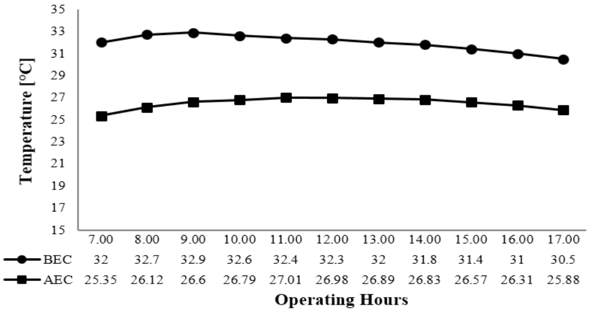


**Figure 10.** Temperature regime of city III before and after evaporative cooling in August.

The results of the performance evaluation of the system are given in Table 4. It is obvious from the results that the highest COP increase is occurred in city II, which reached up to 40.5% in July. On the contrary, the same evaporative cooler only provided maximum 15.5% COP increase in city III. When city I is analyzed, one can see that even the increase compared to BEC is not as high as city II, the COP values AEC is the highest of all three cities. It is because that, city I has the lowest mean temperature values and when the evaporative cooling is applied, the inlet temperature of the condenser is significantly reduced, and therefore COP is greatly increased.

These results indicate that when the evaporative cooling is applied under proper climate conditions, considerable amount of COP increase can be achieved. The comparison between the city II and III shows an important result that even if both cities have high temperature in summer season, the humidity factor is determinant on the evaporative cooling performance.

Increasing the COP provides an increase in cooling capacity and quite importantly reduces electrical consumption of air-conditioning systems. In our study, the cooling capacities of the air-conditioning systems in city I, II and II averagely increased by 7.95%, 14.3% and 5.56%, respectively. The reason behind improving the performance of any system is to spend less energy. Therefore, it is important to reach a level with the application to achieve considerable amount of reduction in electrical consumption.

In this theoretical analysis, it has been shown that, it is possible to reduce electrical consumption by maximum of 17.12% and 15.49% on the average in city II, which is the best case scenario. The average reduction calculated as 9.97% and 6.97% for cities I and III, respectively.

**Table 4.** Performance evaluation of the system for 3 different cities in summer season.

| *City* | *Month* | *COP* | | | *Cooling Capacity [kW]* | | | *Electrical Consumption [kW]* |
|---|---|---|---|---|---|---|---|---|
| | | ***BEC*** | ***AEC*** | ***%*** | ***BEC*** | ***AEC*** | ***%*** | ***% decrease*** |
| *I* | June | 3.78 | 4.35 | 15.1 | 293.4 | 311.2 | 6.0 | 7.85 |
| | July | 3.4 | 4.26 | 25.3 | 280.4 | 308.5 | 10.0 | 12.19 |
| | August | 3.42 | 4.32 | 26.3 | 281.2 | 310.4 | 10.4 | 12.63 |
| | September | 3.83 | 4.35 | 13.6 | 295.2 | 311.2 | 5.4 | 7.20 |
| *II* | June | 3.05 | 4.14 | 35.7 | 267.3 | 304.9 | 14.1 | 15.97 |
| | July | 2.79 | 3.92 | 40.5 | 256.0 | 298.1 | 16.4 | 17.12 |
| | August | 2.84 | 3.89 | 37 | 258.3 | 297.2 | 15.1 | 15.98 |
| | September | 3.23 | 4.14 | 28.2 | 274.1 | 306.1 | 11.6 | 12.89 |
| *III* | June | 3.6 | 3.99 | 10.8 | 287.5 | 300.3 | 4.5 | 5.76 |
| | July | 3.3 | 3.72 | 12.7 | 276.9 | 291.5 | 5.3 | 6.62 |
| | August | 3.17 | 3.66 | 15.5 | 271.9 | 289.7 | 6.5 | 7.72 |
| | September | 3.42 | 3.93 | 14.9 | 281.4 | 298.2 | 6.0 | 7.76 |

The amount of water consumption is calculated with the help of specific humidity values and the air flow rates of air-conditioners (Eq. 5). The results are given in Table 5 for both in terms of consumption per min and total amount for operating hours. It is also possible to use the corresponding data for alternative operating hours. According to the calculations, in city II which has the highest performance increase among the others, the mean total water consumption during the summer season is around 5 tons per day. The consumption is around 3 and 2 tons in city I and III, respectively.

When the evaporative cooling is more effective the consumption and need for water supply increases. Therefore, considering the world's water resources are not as promising, the evaporative cooling needs to be evaluated carefully before the installation to benefit the most of the application. In addition, in order to supply the water, there will be an additional electrical power need to operate the pump. This value needs to be considered while determining the electrical power decrease.

**Table 5.** The amount of water consumption for 3 different cities in summer season.

| | *I* | | *II* | | *III* | |
|---|---|---|---|---|---|---|
| | ***kg/min*** | ***$m^3$/day*** | ***kg/min*** | ***$m^3$/day*** | ***kg/min*** | ***$m^3$/day*** |
| *June* | 4.67 | 2.805 | 8.04 | 4.822 | 2.8 | 1.681 |
| *July* | 6.02 | 3.614 | 9.09 | 5.452 | 3.15 | 1.891 |
| *August* | 6.34 | 3.803 | 8.49 | 5.095 | 3.85 | 2.311 |
| *September* | 5.39 | 3.236 | 6.85 | 4.108 | 3.68 | 2.206 |

## CONCLUSIONS

In this study, the analysis is focused on comparing the 3 specific climate conditions for evaporative cooling application. The aim of using evaporative cooling here is to decrease the inlet air temperature of the condenser units of the air cooled chillers. The benefits of lower inlet air temperature in the chillers are higher COP and cooling capacity, and lower electrical power consumption. Decreasing the inlet air temperature via evaporative cooling is advantageous because it already uses the ambient air, only has a fan and small circulating pump as a moving part. The results show that when evaporative cooling is applied in proper region, the maximum COP increase can reach up to 40.5% thus, increasing cooling capacity by 14.3%. These improvements can also decrease electrical consumption by 17.12%. But in cities with higher humidity, the COP increase can only reach to 15.5%. The highest mean COP after evaporative cooling is calculated as 4.32. In addition, the water consumption should be kept in mind at all times, because it can be significantly high.

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