# Energy Efficient Free Cooling System for Data Centers

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# Energy Efficient Free Cooling System for Data Centers

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***Abstract* - A data center is a facility used to keep computer related equipments. It is estimated that heat production rate of the data center is doubled in every two years and hence the inevitability of the cooling system gets increased. In due course power consumption of a data center is augmented and more cost is spent on the power usage of the cooling system rather than the equipment purchase. As a result power savings for the cooling system is strongly desired. In this paper we conferred two primary free cooling systems namely air economizer and water economizer. A free cooling economizer system uses the outside air which is forced to the data center when outside climate is suitable to meet the ASHRE's cooling requirements. We have also conducted a survey and simulation based estimation using TRACE[TM] Chiller Plant Analyzer Tool. In this study, the energy consumption in a data center using conventional cooling system is compared with Air Economizer and Water Economizer for three different Zones namely *Chicago*, *Atlanta* and *Phoenix* in view of the fact that the outside air is relatively cool most of the year. From the projected result it is observed that both economizers reduce energy and cost when compared with conventional system and the usage of Economizer permits the chiller to shut down or reduce chiller energy load under suitable weather conditions. The results show that Water economizers are shown to consistently outperform air economizer which provides significant improvement in cooling system efficiency and cost at data center. The performance ratio of the conventional, air economizer and the water economizers are 50%, 76% and 79% respectively that shows economizers provide more savings relative to the conventional system.**

***Keywords:* *Performance ratio; Water Economizer; Air Economizer; Energy Consumption; Data Center.***

## I. INTRODUCTION

A data center is a facility used to keep computer associated equipments like server, storage devices, networking devices, backup power supplies, and environmental controls such as air conditioning, fire suppression and security tools. Day - by - day the power consumption of a data center is increased and more cost is spent on its electricity usage rather than the equipment purchase. Lawrence Berkeley National Laboratory has studied the trends of power consumption for a number of data centers [1]. It is estimated that only 30% of the energy is consumed by IT equipments 40% of the energy is by the cooling system and the remaining 30% is used for UPS and lighting. The primary goal of Energy management in the data center is minimizing the energy consumption and maximizing the performance of the active equipment. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends [2] a Data Center room temperature should be in the range of (16°C – 24° C) or (61° F – 75° F) and Humidity range of (40% – 60% RH). This environment can be achieved only by conveying cold air to every piece of equipment. Hence the temperature of all the equipments in the data center never raise beyond its maximum allowable temperature and the room temperature and Humidity level can be maintained in the ASHRE's level.

In the traditional cooling system [3] the servers are mounted on the raised floor with perforated tiles. The racks are lined up as sequential rows forming corridor between the two rows called aisle. The cold air passageway is called cold aisle and the hot air passage way is called hot aisle. Figure 1 depicts the cross section of such hot / cold aisles. In this system air enters at the top of the CRAC(Computer Room Air Conditioning) unit, passes over the cooling coils which is cooled by the chiller plant and the cold air is ejected to the under floor plenum. Fans inside the server draw the cold air upward through the perforated tiles and then absorbs the cold air in front row of server and pushes the equipment generated hot air behind these rows. The departed hot air rises and moves to the intake of a CRAC unit. This approach works well only in low to medium level data center application and does not offer good performance in high level applications. Moreover the mixing of hot and cold air over and around the top of the rack also wastes energy due to overrun of the cooling system.

In this paper we propose free cooling economizer systems that are used in associated with traditional cooling system to reduce energy consumption. A free cooling economizer system uses the outside air which is forced in to the data center when the outside climate is suitable to meet the ASHRE's cooling requirements. When the economizer system starts functioning, reduces or eliminates the working of chiller which consumes the greater part of energy in the air conditioning system.

We have also carried out estimation and simulation based assessment using TRACE[TM] Chiller Plant Analyzer Tool. The purpose of this study is to compare the energy saving in a data center using conventional cooling system with Air Economizer and Water Economizer system for three different Zones namely *Chicago*, *Atlanta* and *Phoenix* in view of the fact that the outside air is relatively cool most of the years and the economizers can be effectively used for maximum possible hours. In these geographical locations, economizers can satisfy a large portion of data center's cooling requirements during winter season. The savings from the economizer depends on the local climate and at the same time as the cold weather increases the number of hours that the economizer is operating is increased.

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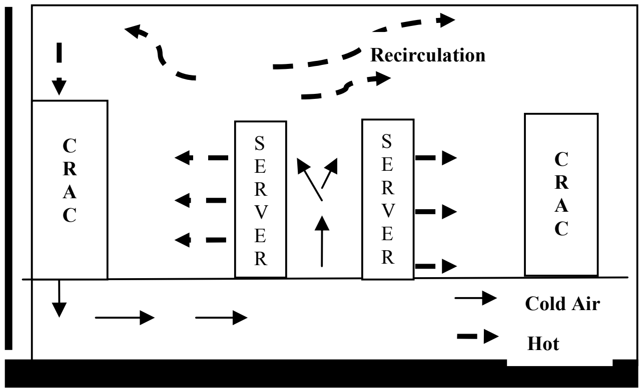


**Figure 1: Traditional Cooling System**

The results show that Economizer system provides greatest savings in *Phoenix* and the least savings in *Chicago*. Water Economizer consumes lowest total Annual power at *Atlanta* and *Phoenix*.

The rest of this paper is organized as follows: Section II denotes the related work focusing on energy efficient free cooling system. Section III explores the two primary methods of cooling systems and evaluation principle. Section IV presents the experimental setup, system requirements and experimented result analysis. Section V gives conclusion

## II. RELATED WORK

Studies have revealed that the thermal management practices like increasing air flow rate, attaching extra fans will be incapable for handling the high thermal load and would also become soundly [4] expensive and alternative methods such as row-based cooling systems have to be implemented.

Liquid cooling was mostly used to reduce power consumption in the data center. Systems with air-to- liquid heat exchangers mounted on the rack to cool the hot air to form a self-contained cooling loop[5] reduces the distance the hot exhaust air must travel before reaching the CRAC units, which minimizes the adverse effects of hot air recirculation. Moving the heat exchanger to the rack relies on air as the heat transfer medium for heat removal from the servers and performance of such systems are limited by airside heat transfer coefficient.

Thermal performance metrics for systems level electronics cooling based on the concept of thermal resistance were formulated and applied to data centers [6]. The metrics considered the spatial uniformity of thermal performance to characterize poor designs causing local hot spots. In another system [7], the wet side economizer was decoupled from the condenser water used to reject chiller heat to cooling towers.

In this system two isolated condenser water systems were used. The wet side economizer condenser water was used to pre-cool the data center return air. The pre-cooled air is then passed through the chilled water supply to cool the air to desired temperature. This decoupled economizer approach requires with more initial investment.

*Xiao Ping Wu* [8] proposed the concept for thermal management of the data center on the basis of the heat pipe based ice storage system and cold water storage. These two types of storage approaches can help to minimize the thermal load on the chiller units and thus save electricity and associated cost.

Recently, data center design with economizers [9] has become an important topic of research in industry and academia. *Yosuke Udagawa* [10] conducted a survey and simulation-based estimation towards the introduction of free cooling system. He compared with the water-cooled central heat source system and the air-side economizer and he found that economizer can reduce power consumption.

*Arman Shehabi* [11] reported energy savings for air-side and water-side economizer use in data centers in several climate zones in *California*. In the result they showed in terms of energy savings, air-side economizers consistently outperform water-side economizers, though the performance difference varies by location.

A report published by Rumsey Engineers in collaboration with Pacific Gas & Electric Company [12] discussed a new design of a data center with economizer. Portable air conditioners were also being used to maintain control in the data center space before an airside economizer was implemented.

## III. FREE COOLING ECONOMIZER SYSTEM

### *A. Air Economizer*

In this section we explore the free cooling economizer system that uses outside air when suitable to meet the ASHRE's cooling requirements. The economizer system suspends or reduces running the chiller and its related equipments that can have significant impact on energy usage. Figure 2 illustrates the cross-section of an air economizer system in which Air Handling Unit (AHU) is placed outside of the data center room to creek in the outside air. The separator inside the room segregates the cold air and hot air which prevents the mixing of cold and warm air within the data center cooling room. A temperature monitor is fixed in AHU that measures the outside air temperature. When the outside air temperature is equal or below the temperature of the air using to cool the equipments the highly efficient fan inside the AHU, draws the outside air in to the data center and exhaust the hot return air generated by the electrical equipment. When the data center is using 100 % outside air, it or eliminates the operation of chiller and its related equipments. When the outside air temperature is greater than the required temperature the chiller must operate to cool the equipments. Air economizer creates some problems related to contaminants entering the data center that spoils the working of the equipments. So that highly efficient filters are required to eliminate the dust that requires additional motor power. More over the movement of

100 % outside air through the system require more fan energy. We also need more humidification system since the water content in the outside air is low during low outside temperature. But this additional energy is very small(1%) when compared with avoiding the working of chiller plant (30 %-40%).

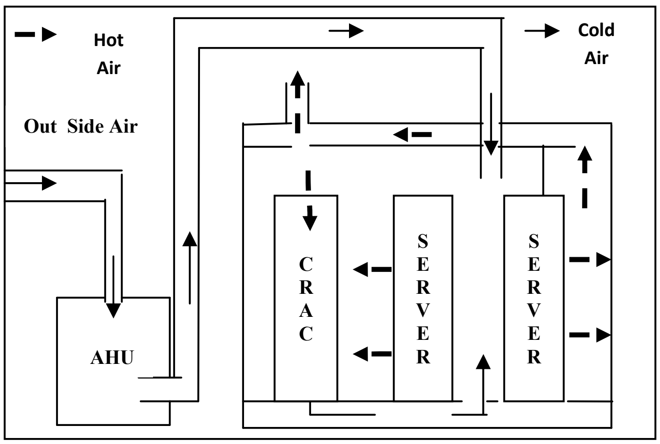


**Figure 2: Air Economizer**

## B. WATER ECONOMIZER

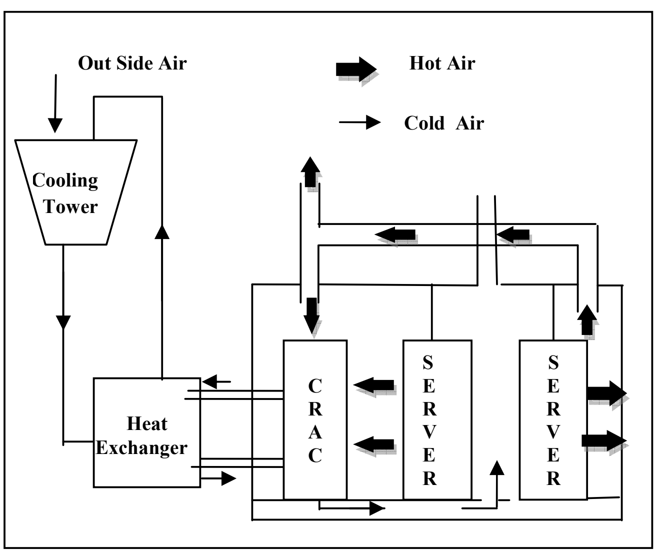


**Figure 3: Water Economizer**

The water economizer system shown in figure 3 consists of cooling tower that has fans inside drawing the outside air when the outside climate satisfies the cooling requirements. The water is chilled by the cooling tower using outside cold air and eliminates or reduces the working of condenser using thermodynamic effect. This cooling water is passed to the cooling coil placed inside the CRAC unit through heat exchanger placed between the data center and the cooling tower which reduces the working of evaporator. Ultimately it reduces the amount of mechanical cooling requirement and reduces the energy cost in the data center. Water economizer is best used in climate with spring and cold winter. It creates the problem of freezing the water in the cooling tower when the outside temperature is very cold and it needs additional energy to operate the fans that draw the outside air.

*B. Evaluation Principle*

The Evaluation principle consider for simulation work are given below.

*Total Power Consumption in the data center*

Each equipment $(E_i)$ in the data center draws air with inlet temperature $T_{in}(i)$ and adds heat by consuming power $P_{in}$ and drives away hotter air with outlet temperature $T_{out}(i)$). As defined in equation (1) the total computing power consumption *(P)* of a data center can be calculated by the sum of the power consumption by all the equipment $(E_i)$.

$$P = \sum P_{in} \quad (1)$$

*Power required for the chiller*

As shown in equation (2) the chiller power consumption can be measured by multiplying the temperature difference between intake and exhaust air in the chiller *($\Delta T$ )*and the air flow through the equipment in cubic feet per minute that can be controlled by internal installation of the fans *(CFM)* and the constant value *3.17*.

$$P_{chiller} = 3.17 * \Delta T * CFM \quad (2)$$

*Power required for Fan*

The power required for each fan P is defined as in equation (3) where $CFM = 3.1\, W/\Delta T$, CFM is Cumulative cubic feet per minute of airflow consumed by all equipment in the rack where ΔT is difference in Temperature rise between input air and output air and η is the efficiency of the fan .

$$P_{fan} = (CFM * PSI * 746)\left(\frac{229}{\eta}\right)W \quad (3)$$

*Cooling Power of CRAC*

The efficiency of the heat removal depends on the coefficient of cooling performance (CoP) at the supplying cold air $T_{sup}$ where CoP is the ratio of the heat removed from a system to the work required to perform the removal and $P_{in}$ is the heat rate of the air that enters the CRAC. At any given point the cooling power of CRAC is defined in equation (4).

$$P_{CRAC} = \frac{P_{in}}{CoP(T_{sup})} \quad (4)$$

*Relative Humidity Calculation*

The Relative Humidity (RH) defined in equation (5) is the ratio of the actual water vapor pressure to the saturation water vapor pressure at the prevailing temperature. RH is usually expressed as a percentage rather than as a fraction. $P_S$ Saturation vapor pressure *= 610.78 *exp( t / ( t + 238.3 ) *17.2694 )* and *p* is water vapor pressure .

$$RH = \frac{P}{Ps_s} * 100 \quad (5)$$

*Humidification and Dehumidification Power*

Humidification and dehumidification requirement of the CRAC units is determined by the RH level to be maintained in the data center space, and the amount of energy and moisture intake at the inlet. Since it is necessary to maintain the server inlet at the ASHRAE's recommended level, moisture must be removed or added to the air as and when required as the outside air being brought into the data center is not necessarily within the range. If dehumidification is required, moist air should be cooled to a temperature below its initial dew point. For humidification, moisture is added to the supply air at the inlet of the CRAC and then cooled to operating temperature of the data center.

*The Performance Ratio*

The Power Usage Effectiveness (PUE) is defined as the ratio of the total power consumed by a data center to the power consumed by the IT equipment that populates the facility. The Total Facility Power is defined as the power measured at the utility meter i.e., the power dedicated solely to the datacenter. The IT Equipment Power is defined as the equipment that is used to manage, process, store, or route data within the data center. Data center Efficiency (DCE) is defined as the reciprocal of PUE.

$$PUE = \frac{Total\ Facility\ \ Power}{IT\ Equipment\ Power}\ x\ 100\% \quad (6)$$

$$DCE = \frac{IT\ Equipment\ Power}{Total\ Facility\ Power}\ x\ 100\% \quad (7)$$

## IV. IMPLEMENTATION DETAILS

### A. Experimental Environment

The energy consumption of each scenario is simulated using TRACE[TM] energy program. TRACE [TM] software is the complete load, system, energy and economic analysis program that compares the energy and economic impact of such building alternatives as architectural features, CRAC systems, building utilization or scheduling and economic options. It includes ASHRAE Standards and envelope libraries, gbXML (green build XML) imports, weather files, templates, ASHRAE 62.1-2010 Ventilation Rate Procedure, Building Information Modeling (BIM) and more.

*System Requirements:* Pentium III or higher processor, 500 MB of free hard disc space, 1 GB of RAM, 800 x 600 or greater monitor resolution, Microsoft Windows 2000/XP/Vista Operating System. For each scenario, the model calculations assume 12,000 square feet of data center with a server load of 3MW and an average data center density is assumed to be 250 watts per square feet.

To evaluate the energy saving in the data center, the Humidity & Temperature [13] values for the three relatively cool most of the year. These geographical locations namely *Chicago, Atlanta, and Phoenix* were considered in view of the fact that the outside air satisfies a large portion of data center cooling requirements during winter season.

Energy consumption is calculated as the sum of the loads generated by IT equipment, Humidification, Pump, Chiller use, Fan operation, Transformer and building lighting. All the three scenarios assume conventional humidity restrictions recommend by ASHRAE (ASHRAE 2008). Table 1 gives the basic parameters like Relative Humidity, CRAC supply air and return air temperature, Entering cold water temperature and maximum cold aisle temperature value for Conventional, Air and Water Economizer system.

TABLE 1. Basic parameters for the various scenarios

| **Initial Conditions** | **Conventional** | **Water Eco'r** | **Air Eco'r** |
|---|---|---|---|
| CRAC relative humidity, RH% | 45 % | 40 % | 40 % |
| CRAC return air temp | 75° F | 84° F | 84° F |
| CRAC supply air temp | 56° F | 64° F | 64° F |
| Entering water temp F | 45° F | 55° F | 55° F |
| Maximum cold aisle Temp | 65° F | 77°F | 77°F |

It is required to maintain the Relative Humidity (RH) of the data center room value to be 40% – 60%, as recommended by the ASHRAE standard. Initially the Relative Humidity for the conventional system is set as 45 % and 40 % for the economizer system. Most of the CRACs regulate the cooling function based on sensing the return air. The CRAC return intake temperature and CRAC supply air temperature from the CRAC is measured and kept as 75° F return air temperature and 56°F supply air temperature in the conventional system. These values are raised to 84°F and 64°F respectively while using the Economizers. Higher air temperature allows CRAC to run more efficiently. Because less compressor energy is needed to maintain higher CRAC output temperature. Moreover higher temperature difference between the return air and the cooling coil improves heat transfer. Chilled water temperature or Entering water temperature of 45° F which is a standard value for the data center operation, is used in conventional system and it is increased by 10° F for the economizer systems. This increases needed air flow rate that ultimately increases the usage of economizers for more hours. Entering water temperature is also raised by 10° F in conventional system and

18°F in Economizer system since the compressor energy requirement is reduced to maintain the higher water temperature. Cold Aisle temperature is measured at the front, bottom, and the top of the rack and the average Cold Aisle temperature value is calculated.

*B. Experimental Result and Discussion*

Table 2: Disaggregated Energy Usage

| KW hrs / Year | CHICAGO | | | ATLANDA | | | PHOENIX | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Conventional** | **Air Eco'r** | **Water Eco'r** | **Conventional** | **Air Eco'r** | **Water Eco'r** | **Conventional** | **Air Eco'r** | **Water Eco'r** |
| Humidification | 813 | 96 | 80 | 485 | 63 | 53 | 729 | 49 | 37 |
| Chiller | 4335 | 2767 | 1346 | 4375 | 2839 | 2072 | 4394 | 3182 | 1894 |
| Pumps | 961 | 271 | 718 | 948 | 268 | 607 | 961 | 307 | 730 |
| Cooling tower | 283 | 340 | 296 | 385 | 344 | 346 | 362 | 366 | 367 |
| Fans | 4980 | 2405 | 1921 | 5048 | 2420 | 1947 | 5098 | 2406 | 1968 |
| **Total Cooling Energy** | **11,372** | **5879** | **4361** | **11241** | **5934** | **5025** | **11544** | **6310** | **4896** |

Results from each scenario model are presented in Table 2 as the disaggregated energy usage of equipments like Humidifier, Chiller, Pumps, Cooling Tower and Fans. Result shows that the conventional system consumes double the energy compared to the economizer system. Air Economizer needs more Fan energy than Water Economizer, since it needs more fan motor power to draw the 100 % outside air by Air Handling Unit (AHU). Air Economizer needs more humidification energy if Relative Humidity (RH) level is narrowed between ASHREs RH levels 40 -55 %.

The usage of both Air and Water Economizer permits the chiller to shut down or reduce chiller energy load under suitable weather conditions. The reduction of chiller operating hours reduces the consumption of chiller energy.

Figure 4, 6 and 8 shows that the disaggregated energy consumption for the above three scenarios at various locations such as *Chicago*, *Atlanta* and *Phoenix* respectively. It illustrates the energy requirement of the cooling system components, namely humidifier, chiller, pumps, cooling tower and fans when economizer is operating. The usage of Economizer is controlled by the temperature of the outside air.

The Annual Energy cost is evaluated for each of the three scenarios assuming that data center building is located in *Chicago, Atlanda* and *Phoenix* and the values are shown in Figure 5 , 7 and 9 . Result shows that in all the three locations Energy cost is reduced when economizer is implemented . The economizer usage hours depends on the temperature of the outside zone. Economizer system provides greatest savings in *Chicago* and the least savings in *Atlanda*. .

The Power Usage Effectiveness (PUE) or the performance ratio is the ratio of total data center Power consumption to the IT equipment Power Consumption. Lower the ratio implies better energy utilization of the HVAC system. Data center Efficiency (DCE) is defined as the reciprocal of PUE. The PUE and DCE values are shown in figure 10 and 11. Result shows that 2.0 PUE or 50% DCE, 1.32 PUE or 76% DCE and 1.27 PUE or 79% DCE for the conventional , Air and Water Economizer respectively. The result shows that economizers provide more saving relative to the traditional system. It is important to know that, even a very small change in the ratio gives very significant saving in energy consumption.

## V. CONCLUSION

The design with free cooling economizer system is in it's early stages. In many parts of the world Economizers have been successfully installed in the data center. In this investigation three different locations namely *Chicago*, *Atlanta*, *Phoenix* were considered for evaluating the saving in energy that can be accomplished if the Economizer is used. Even though the usage of both air and water Economizer permits the chiller to shut down or reduce chiller energy load under suitable weather conditions, the results show that Water economizers consistently outperform air economizers which provides significant improvements in cooling system efficiency and cost at data center. The savings from the economizer depends on the local climate and at the same time as the cold weather increases the number of hours that the economizer is operating is increased. Result shows that Economizer system provides greatest savings in *Chicago* and least savings in *Atlanda.* The performance ratio of the conventional, air economizer and the water economizers are 2.0 PUE or 50% DCE, 1.32 PUE or 76% DCE and 1.27 PUE or 79% DCE respectively that shows economizers provide more saving relative to the traditional.

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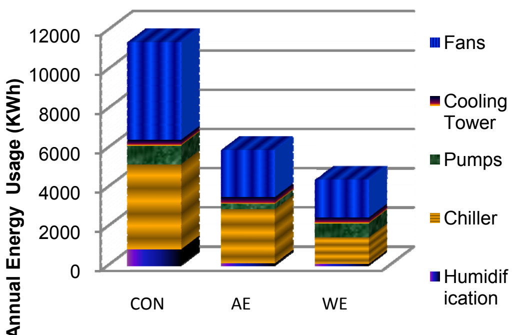


**Figure 4: Disaggregated Energy Use for CHICAGO**

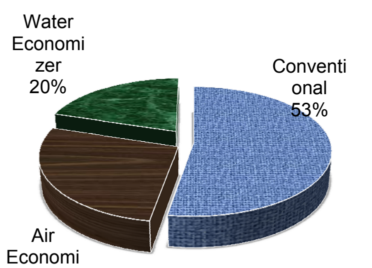


**Figure 5: Annual Energy Cost - CHICAGO**

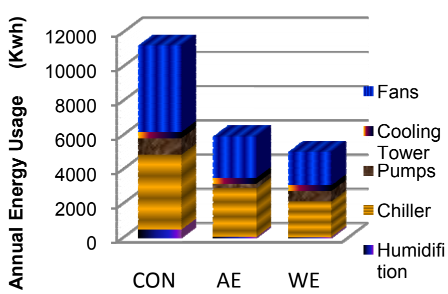


**Figure 6: Disaggregated Energy Usage for ATLANDA**

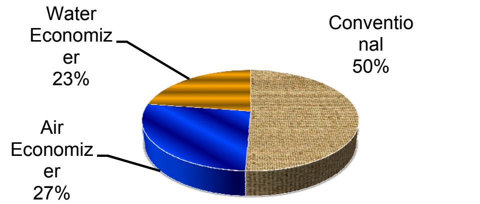


**Figure 7 :Annual Energy Cost - ATLANDA**

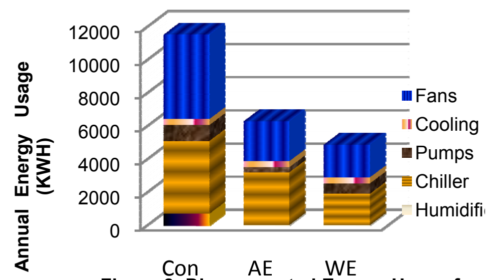


**Figure 8: Disaggregated Energy Usage for PHOENIX**

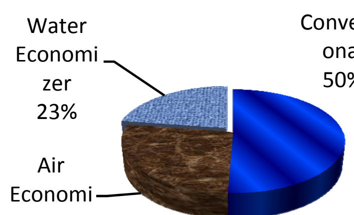


**Figure 9: Annual Energy Cost -PHOENIX**

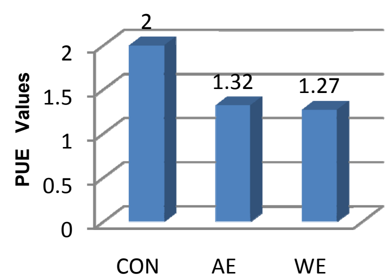


**Figure 10: PUE Values for the various scenarios**

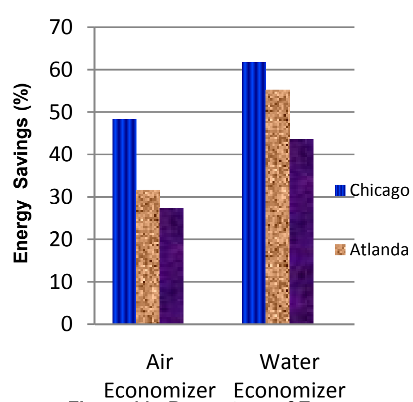


**Figure 11: Percentage of Energy Savings in all the three Locations**