Energy Evaluations between Air-Cooled Vs Water-Cooled Cooling Systems in Non-Residential Buildings

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SUMMARY

Present study is devoted to specifying the optimization of use of air-cooled vs. water-cooled cooling systems based on the climatic region classification. It proposes affecting design criteria's, which could be implemented in HVAC Uniform code for Middle East, and especially for the Egyptian HVAC and Energy codes. It yields selection criteria's for typical size ranges, where a water-cooled cooling systems are more economical than air-cooled systems and vise versa. This concept has impacts on energy efficiency and conservation. Study is concerned to the field survey, and energy analysis of non-residential buildings in Egypt, covering seven main climatic regions, on which, each region shall be defined for specific cooling system configurations. One of the conclusions is that for newly designed projects, located almost in all Egyptian climatic regions, with any cooling capacities ,could be designed based on water-cooled system with minimum initial and running cost taking into consideration the availability of different water sources in Egypt.

INTRODUCTION

Energy demands in buildings require clear identification of the energy measuring factors with potential verification of each factor in terms of energy saving and the economic revenue [1]. First, factors those required for comfort control and are easy to implement by codes. Second, factors that based on promoting changes in needs and habits of occupants, equipment, operating schedules and control of temperature settings. Third, those factors that are related to the Electro-Mechanical systems, which are the most effective terms on total energy, use and demands [2]. Field surveys, theoretical analyses and parametric runs were performed on different building types in Egypt [3]. Most of these analyses were related to the first group of factors. While, economic evaluations of cost impacts versus anticipated benefits were carried out by the local authorities [4]. The second group of factors has been preliminary treated, since these factors require adaptations in the habits of occupants. Finally, third group of factors was considered since these factors have strong potential on global energy efficiency without affecting citizen's habits. Egypt country was elected as a base case in present study.

Climatic Classifications

Egyptian climate as a sample case considered as Hot and Dry climate while the north region adjacent to Mediterranean Sea is hot and humid climate due the effects of sea [5]. Bioclimatic classifications based on temperatures, humidity and solar heat gains, for Egypt show main seven regional climates [6] on which human biological and physiological impacts were studied by many investigators to evaluate, and justify the acceptable human comfort limits [7]. Climatic Regions are indicated in Figure 1 .

Region [1],
Mediterranean Sea climates.
22-to-28^{O}C dbt & 50-to-80%RH
Region [2],
Upper and Lower west desert.
30-to-38^{O}C dbt & 40-to-60%RH
Region [3],
Upper Egypt valley at Sudan borders.
30-to-45^{O}C dbt & 15-to-40%RH
Region [4],
Southern-Upper Egypt valley.
31-to-42^{O}C dbt & 20-to-55%RH
Region [5],
Northern-Upper Egypt valley.
30-to-40^{O}C dbt & 30-to-55%RH
Region [6],
Delta Region.
22-to-37^{O}C dbt & 45-to-65%RH
Region [7],
Sinai, Red Sea Zone.
23-to-41^{O}C dbt & 17-to-50%RH

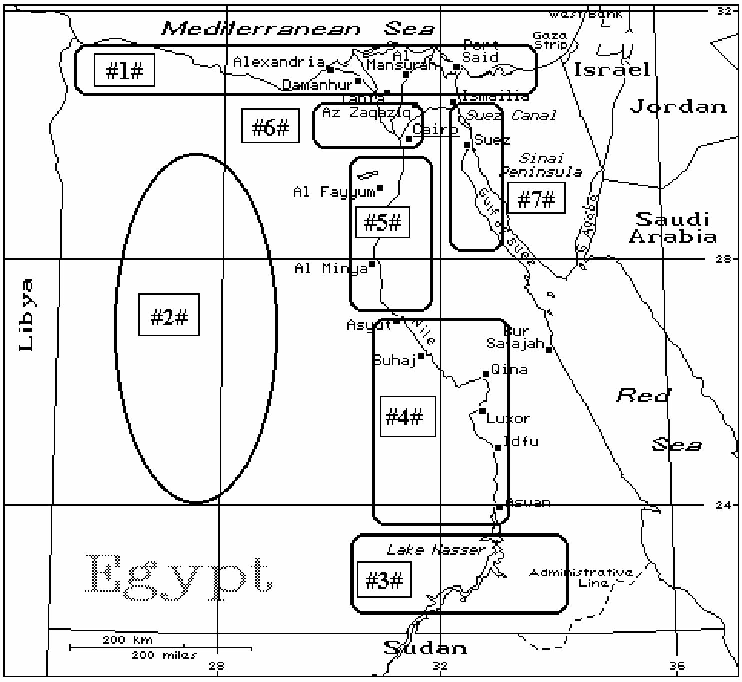

Figure 1. Climatic Regions Classifications in Egypt at Average Summer Conditions

Heat Release Concept

In dry coolers ambient air is used to remove heat by convection process, while in wet coolers heat removal achieved by ambient air in combination with water in evaporation processes. Where, heat release is a function of the wet bulb temperature, WBT, of ambient air and of air capacity for vapor transport. In a Hot & Dry climate, WBT is usually much lower than dry bulb temperature, DBT. Accordingly, lower effective heat sink temperature can be achieved with wet coolers than with dry coolers [8]. On the other hand, wet coolers require water feed & drainage systems, water treatment, filtration units, piping between cooling units and towers, and extra controls leading to additional complexity, together with installation and maintenance costs, that make it less acceptable and less economical than dry coolers. In Egypt cooling towers are not considered for installations smaller than 1500 kW [2].

Thermal load characteristics survey and common practices in Egypt [3] demonstrated ranges of required air-cooled cooling equipment capacities, especially when these equipment are located at ambient DBT over 45^{O}C with the presence of sandy storms. Figure 1 shows real energy efficiency ratios, EER's of in-service air cooled cooling units starting from ARI-Conditions and up to 48^{O}C outdoor operating conditions representing different locations in Egypt. Fitted curves listed in Figures 1 & 2 represent the following different cooling systems that have same cooling capacities, operating schedules and indoor conditions:

[A], Water cooled reciprocating or screw chillers ranged from 70kW-to-525kW nominal cooling capacities, new installations, sand filters and chemical treatment were utilized in condenser side, and operating at 80%-to-100% full loads.

[B], Water cooled reciprocating direct expansion units ranged from 17kW-to-100kW nominal cooling capacities, new installations, sand filters and chemical treatment were utilized in condenser side, and operating at full loads.

[C], Water cooled reciprocating or screw chillers ranged from 70kW-to-525kW nominal cooling capacities, old installations, sand filters and chemical treatment were not utilized in condenser side, and operating at 80%-to-90% full loads.
[D], Water cooled reciprocating direct expansion units ranged from 17kW-to-100kW nominal cooling capacities, old installations, sand filters and chemical treatment were not utilized in condenser side, and operating at 90% full loads.
[E], Air cooled reciprocating direct expansion units that are new &/or have five years old installations, operating at 80%-to-100% full load covering nominal cooling capacities from 17 kW-to-67 kW..
[F], Air cooled reciprocating water chillers that have five years old installation, operating at full load covering nominal cooling capacities from 17 kW-to-525 kW.

Figure 2 show that air-cooled cooling systems that ranged from 17 kW to 525 kW, When operated at tropical outdoor temperatures and with presence of sandy storms will have a new cooling ratings and performances lower than that listed in the original catalogues [2,8]. This means losing sensible cooling capacities and increase power consumptions significantly, On the other hand, the figures show that water cooled units have a stable cooling capacities as its operation principles are based on evaporative cooling that is affected only by wet bulb temperature. Wet bulb temperatures are almost stable and ranged from (22 ^{O}C-to-26^{O}C). Figure 3 shows actual behavior in term of the coefficient of performances, COP's of the same cooling systems compared with ARI-Conditions and up to 48 ^{O}C. Both Figure 2 and 3 show that water-cooled systems have good sustainability in hot and dry climate as they consume low energy up to 0.88 kW/T.R (1.0 T.R=3.5 kW cooling) ,when utilizing evaporative systems rated at 90% or more saturation efficiency [1].

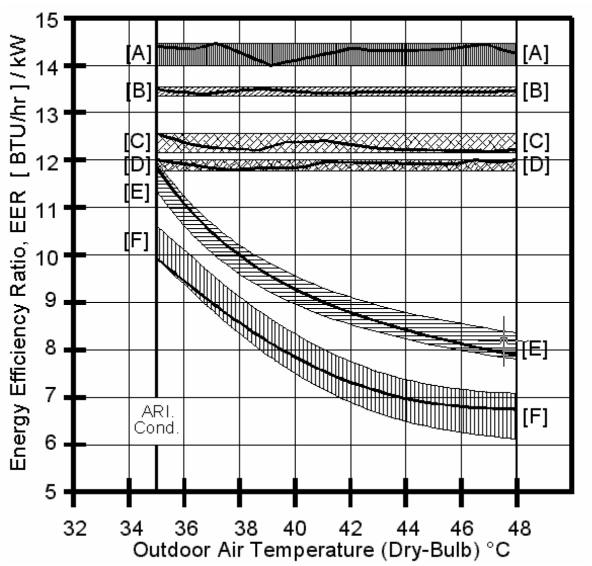

Figure 2, Changes in EER with increase of outdoor DBT compared with ARI-Conditions

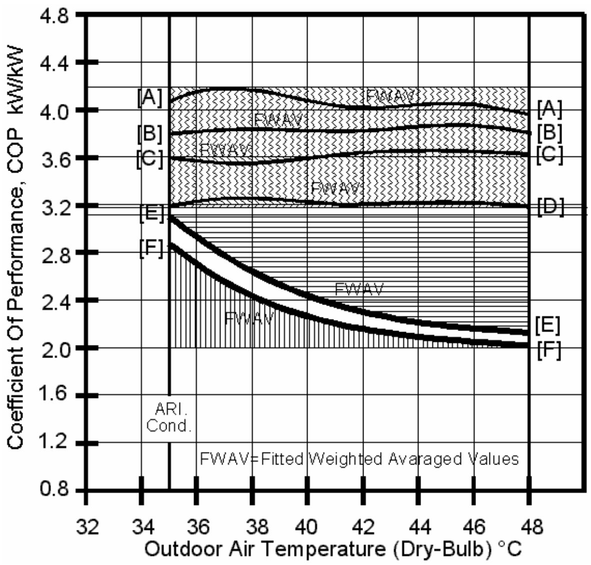

Figure 3, Changes in COP with increase of outdoor DBT compared with ARI-Conditions

Comparative Study Standardization

As this study primarily presents an economic evaluation of air-cooled and water-cooled systems, a number of assumptions are used to make the investigation more manageable and appropriate; the more important assumptions can be summarized as:

- In air-cooled units; the study covers direct expansion and chilled water systems for 100% loading units in operation up to 900 kW, 255 TR cooling capacity.

- In water-cooled units; the study covers direct expansion and chilled water systems for 100% loading units in operation range 500-to-3500 kW, 140-to-1000 TR cooling capacity.
- Ambient Conditions, dry bulb temperatures ranged from $39^{O}C$ to $42^{O}C$, & Wet Bulb temperatures ranged from $23^{O}C$ to $26^{O}C$.
- Indoor Conditions, dry bulb temperatures ranged from $24^{O}C$ to $26^{O}C$, & Relative humidity ranged from 45% to 55%.
- Systems Conditions, All units utilize refrigerant R-22 using Reciprocating or Screw compressors types while, water cooled types over 2000 kW, 570 TR cooling Capacity utilize centrifugal compressors.
- Supply air temperatures from direct expansion units are not more than $10^{O}C$.
- Supply/Return water temperatures in hilled water systems $6\,^{O}C$ /$12\,^{O}C$.
- Analyses for the life cycle cost, and maintenance do not consider any interest or inflation rates for simplification purposes and render the study consistent with other approaches and also due to the lack consistent projections for interest and national inflation rates.
- Annual operating costs consist of the cost of the electricity, water use and operation, maintenance charge per year of operation.
- Annual consumption of electricity and water are estimated on the basis of an equivalent full load operation of plant over a specified number of hours of operation per year.

Comparative Study Methodology

This study involves the evaluation of life cycle cost of air-cooled and water-cooled direct expansion and chiller plants of various sizes up to 3500 kW, 1000 TR. The cost analysis is performed in terms of customer [CI] and national [NI] cost indexes. Customer cost index reflects all expenses born by individual property owner the capital equipment of the chiller plant, installation, operation and maintenance over specific life time, and includes the new charges for installation and connecting the electrical capacity required by the plant. While national cost index reflects all expenses for equipment and labor at national level to install, operate and maintain cooling plant over same life time. It is rather similar to customer cost index except that the annual operating cost is estimated on the basis of the national cost for producing electricity and water as per the following governing equations:

$$CI = \{[CC+I]/TR\}+\{([LT]*[AC]+[NC]*[ER])/TR\} \quad \textbf{Eq.1}$$

$$NI = \{[CC+I]/TR\}+\{([LT]*[AC])/TR\}+\{[ER]*[CAE]\} \quad \textbf{Eq.2}$$

$$[AC]_{\text{air cooled}} = [ER*TR*HRE*EC]+OP+MC \quad \textbf{Eq.3,}\ \text{Customer}$$

$$[AC]_{\text{air cooled}} = [ER*TR*HRE*EN]+OP+MC \quad \textbf{Eq.4,}\ \text{National}$$

$$[AC]_{\text{water cooled}} = [ER*TR*HRE*EC]+[W*TR*HRE*WC]+OP+MC \quad \textbf{Eq.5,}\ \text{Customer}$$

$$[AC]_{\text{water cooled}} = [ER*TR*HRE*EN]+[W*TR*HRE*WN]+OP+MC \quad \textbf{Eq.6,}\ \text{National}$$

Where:

I	Installation cost **(L.E)**
CI	Customer cost Index **(L.E)**
CC	Capital equipment Cost **(L.E)**
TR	installed cooling capacity **(TR)**
LT	Life Time of equipment **(Years)**
AC	Annual operating Cost **(L.E)**
NC	New connection fee per kW Capacity **(L.E/kW)**
ER	Electrical Requirement per unit (T.R) capacity **(kW/TR)**
HRE	Equivalent hours of operation per year at full load **(h/yr)**
EC	Electricity Cost to customer **(L.E/kWh)**
W	Water consumption rate per unit (T.R) capacity **(l/h/TR)**
WC	Water Cost to customer **(L.E/m^3)**
OP	Cost of operator per year **(L.E)**

MC	Maintenance Cost per year (labor + spare parts), **(L.E)**
CAE	Cost of installing additional electrical capacity **(L.E/kW)**
EN	National cost for producing electrical energy **(L.E/kWh)**
WN	National cost for producing domestic water (**L.E/M^3**)

It is evident that accurate evaluations of customer and national cost indices requires detailed and accurate information of all the component costs that contribute on life cycle cost. This information was provided by HVAC contractors, equipment agents and consultants.

ENERGY ANALYSIS

a. Air-Cooled Units are available in one size of up to 800 kW, 255 TR in single packaged units. The majority of the units on the market are driven by reciprocating or screw compressors, one or more compressors per unit, for most installations in the range of 350-to-1750 kW, 100-to-500 TR . An analysis of the packaged units available on the market reveals a kW/TR requirement, excluding the chilled water pump and the air side, as shown in Figure 4. The figure indicates that the electrical requirements fall between 1.40-to-1.70 kW/TR.

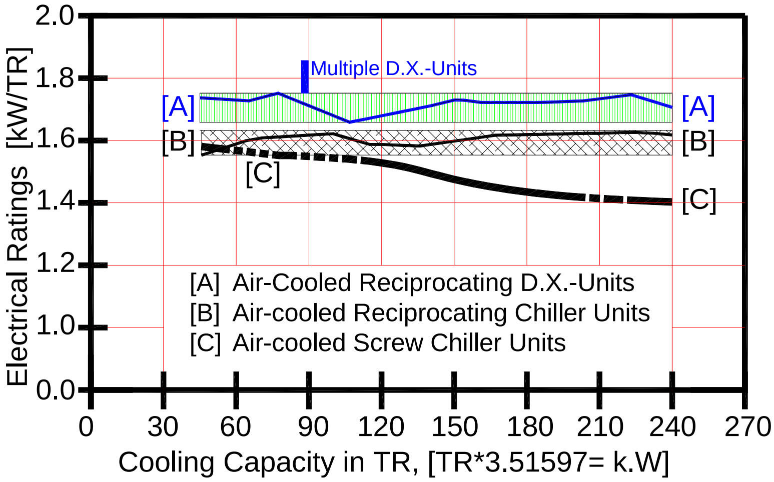

Figure 4, Electrical Average Ratings of Air-Cooled Units

b. Water-Cooled Units are available in sizes of up to 2000 kW, 570 TR in packaged units.

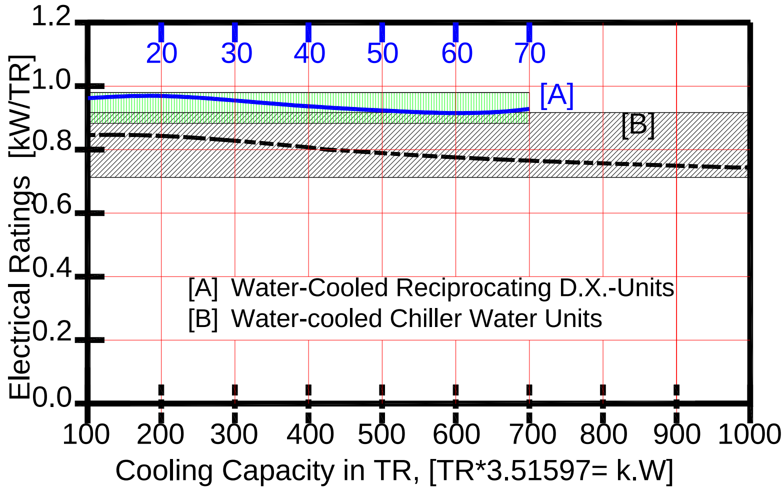

Figure 5, Electrical Average Ratings of Water Cooled Units

Reciprocating or screw compressors are used in the small size units while centrifugal compressors are common in the large size units. Due to the diversity in the type and size of compressors and other components, the electrical requirement of the cooling plant is expected to vary accordingly.

Cooling plant components that require electricity are primary the compressor, the condenser water pump and cooling tower fan. These components in water-cooled units are rather detached physically and operationally and their sizing is somewhat site dependent. Collected data reveal a spread in the energy requirements of the D.X or chiller only, as shown in Figure 5. The kW/TR requirement falls generally between 0.80-to-0.90, kW/TR. There is a tendency for the kW/TR requirement to drop with the increase in the size of the chiller though this drop is rather insignificant.

c. Cooling Towers have similar analysis of electrical requirements of the cooling tower fans for cooling towers of 350-to-7000 kW, 100-to-2000 TR in capacity gives the spread in results as shown in Figure 6. It is observed that the kW/TR requirement is around 0.1 kW/TR for 750 kW, 215 TR capacities, and falling off to 0.094 kW/TR for a 3000 kW, 850 TR capacity unit. These values are common for the usually utilized induced draft cooling tower design.

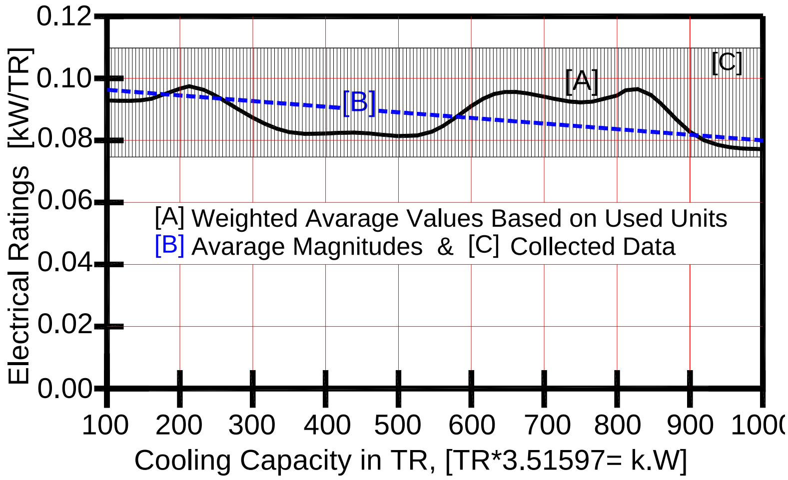

Figure 6, Electrical Approximated Ratings of Wet Cooling Towers

d. Water Pumps are strongly site dependent, the location of the cooling tower relative to cooling unit and the extent of piping, its size and number of bends, valves, etc. between the two units dictates the size of pump required. It is expected that there would be a very wide variation in the sizes and the electrical requirements of pumps for different installations. A review for the past ten years installations revealed a spread in the kW/TR requirement between 0.05 and 0.17 a generalized value for condenser water pump requirement could be within 0.10 kW/TR.

COST ANALYSIS

Capital **C**ost of **A**ir-cooled **U**nits in sizes of 150 KW, 40 TR and higher is shown in Figure 7. The values quoted in the figure are contractor price figures for packaged units delivered to site. The prices are for the packaged units with its air-cooled condenser, electrical panel and cabling. Figure 6 shows that, for chillers with reciprocating compressors in the capacity range of 150-to-530 kW, 40-to-150 TR, the capital cost ranged from 500-to-700 L.E/kW, 1750-to-2500 L.E/TR.

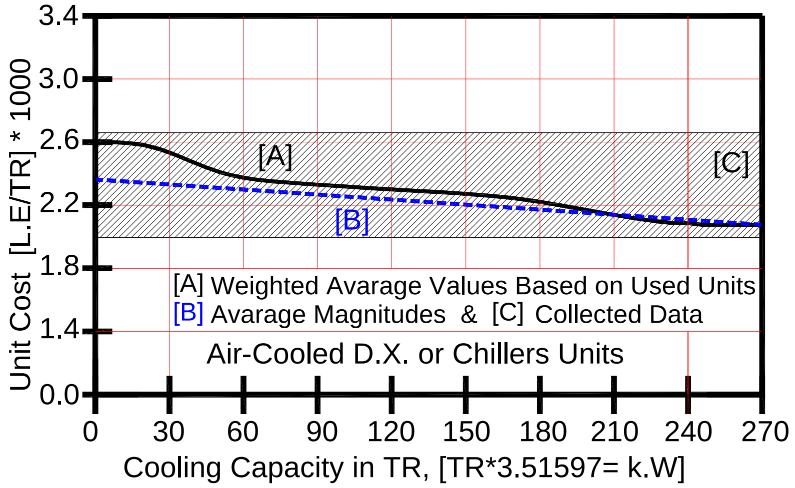

Figure 7, Predicted Cost per Cooling Capacity for Air-Cooled Packaged Unit

Capital **C**ost of **W**ater-Cooled **U**nits figures delivered to site are in Figure 8 The cost figures are for individual packaged units in the capacity range of 150-to-3000 kW, 40-to-850 TR. Installations of large capacities (3000 kW, 850 TR & up) and even those in the mentioned capacity range usually consist of a number of packaged units appropriately chosen to have a competitive L.E/TR cost. It can be observed from Figure 6 that there is a wide scatter in the cost figures, with the average values showing a distinct drop in the L.E/kW cost with the increase in capacity of the packaged unit. This cost starts at around 500 L.E/kW, 1750 L.E/TR for a 350 kW, 80 TR unit and drop off to around 350 L.E/kW, 1225 L.E/TR for units in the 1700-to-3500 kW, 485-to-1000 TR range.

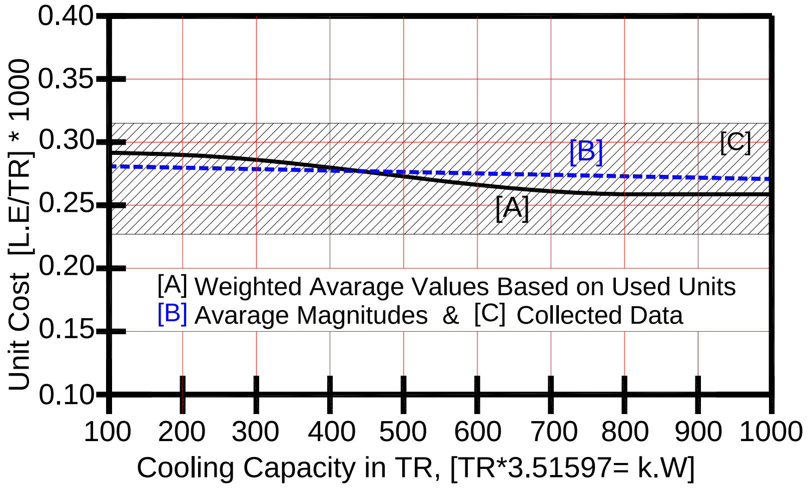

Figure 8, Predicted Cost per Cooling Capacity for Water-Cooled Packaged Unit

Capital **C**ost of **C**ooling **T**ower depends on the type of cooling tower specified for the installation. Capital cost for cooling tower is shown in Figure 9. The figure shows a variation in capital cost from around 125 L.E/kW, 440 L.E/TR for a 350 kW, 100 TR installations to around 100 L.E/kW, 350 L.E/TR for sizes 2800 kW, 800 TR and over. Pump cost varied between 10-to-25 L.E/kW, 35-to-88 L.E/TR, Piping cost has greater variations, from 20-to-65 L.E/kW, 70-to-225 L.E/TR. Other capital equipment costs are water treatment and filtration units that varied around 25 L.E/kW, 88 L.E/TR.

Water-cooled Units require a built-in space as opposed to air-cooled units, which are mounted directly on the roof. This space is normally provided or a separate plant room built, then the expense could add some 30-to-50 L.E/kW, 100-to-175 L.E/TR to the total installation cost of water-cooled units. This cost is not considered in the analysis.

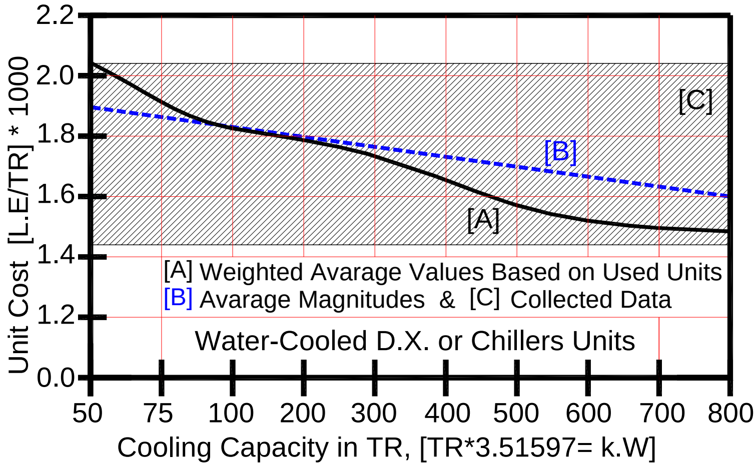

Figure 9, Predicted Cost per Cooling Capacity for Wet Cooling Towers

Installation & commissioning cost is difficult to determine with any certainty and vary among contractors and different installations. This is because some contractors include it within the capital cost or consider it as a certain percentage of the equipment cost. It is deduced that the cost of the installation and commissioning of air-cooled chillers is in the range of 30-to-50 L.E/kW, 100-to-175 L.E/TR. Installation size should have little effects on cost since large capacity installations would be made up a number of packaged units with each unit requiring the same amount of effort in installation and commissioning. A similar analysis for water-cooled units reveals that the cost for installation of all the components of the plant and its commissioning is in the range of 60-to-70 L.E/kW, 210-to-245 L.E/TR for large capacity installations.

POWER AND WATER COST

In Egypt, the energy consumption for residential and commercial private buildings contributed with 35% of the total energy generated [3] the larger portion of this energy was consumed in the cooling processes. Therefore, the residential and tertiary sector is one of the most energy intensive sectors. Nevertheless; the new buildings will be constructed in accordance with new energy efficiency codes. Energy consumed by the older buildings themselves is very high. Heat losses in buildings are caused, not only by low standards building materials and construction, but also by poor insulation of heat and lack of energy efficiency awareness that presents the main reasons for high energy consumptions in residential buildings and describes the traditional methods that have been employed to achieve energy conservation in residential sector. The running cost relating to the electricity and water used by cooling units over a one year period is estimated according national cost. The water consumption in water-cooled units is estimated to be 0.013 m^3/hr/TR for make-up water, while cost of air-cooled units could be similarly obtained, taking into considerations that water cost is subsidized by government.

CONCLUSIONS OF THE RESULTS

Simple analysis of air-cooled units and the effect of various parameters on their respective costs were carried out using simple parametric analysis with the ratio $(CI)_{air\ cooled} / (CI)_{water\ cooled}$ & $(NI)_{air\ cooled} / (NI)_{water\ cooled}$. It is observed from analyses that the capital equipment and installation costs represent a small fraction of the CI and NI. Thus, the variation of cost with cooling capacity should have insignificant effect on the analysis as indicated in Figure 10.

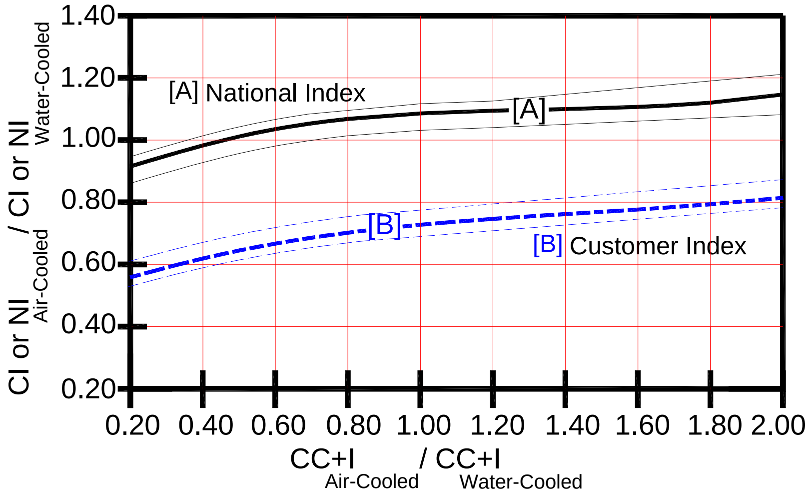

Figure 10, Effects of capital and installation costs on the customer and national index

There is a general consensus among contractors that air-cooled units are cheaper to operate and maintain, there is no clear idea of the actual cost. The figures obtained showed large variations. This is because operation and maintenance contracts are not based on the equipment only but also on site conditions. Also, contracts are usually awarded for the operation and maintenance of the total HVAC system and often these contractors for labor only with the spare parts to be paid by the customer according to use.

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