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*Review Article*

# INDIRECT EVAPORATIVE COOLING – A PAST REVIEW

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The phenomenon of evaporative cooling is a common process in nature, whose applications for cooling air are being used since the ancient years. In fact, it meets this objective with a low energy consumption, being compared to the primary energy consumption of other alternatives for cooling, as it is simply based in the phenomenon of reducing the air temperature by evaporating water on it. This process can be an interesting alternative to conventional systems in these applications where not very low temperatures are needed, like the case of air-conditioning during the summer. In this paper various types of direct and indirect cooling methods are reviewed to understand the various ways to attain cooling by these methods and provide alternative.

***Keywords:*** Evaporative cooling, Low energy consumption, Primary energy consumption

## INTRODUCTION

The environmental impact associated to the use of energy from conventional fossil origin, the energetic and economic dependency on non-renewable sources, lead to the necessity of reducing the energy consumption, maintaining the current targets and necessities of each activity that require the use of energy. Figures about the energy consumption by fields show that from 20% to 40% of the total energy demand in developing countries is generated in buildings, depending on the climatic conditions (Pérez-Lombard *et al.*, 2008). Moreover, due to the high number of users of the building sector, an improvement on the energy efficiency of the systems leads to an important decrement on the energy consumption, thus being this sector one of the most interesting fields to focus the activity to improve the energy efficiency. However, not only the economic savings have to be considered in the study of the improvements in energy efficiency, whose profitability is commonly uncertain, but also the reduction in the environmental impact or in the misused of natural resources implied (European Parliament and of the Council, 2002). Despite the fact that the priority of the new dispositions

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introduced for energy management, new devices and generators among others, is to reduce the energy consumption in buildings, they must ensure a proper comfort level and well being of their users (EN ISO 7730, 2005). Consequently, it should be considered the introduction of systems that permit condition the hygrothermal environment of the rooms, maintaining an adequate indoor air quality and thermal comfort, with low energy requirements, when providing energetic viable solutions to obtain a proper thermal environment in buildings.

## HISTORY OF EVAPORATIVE COOLING

Many examples of the application of the phenomenon of evaporative cooling can be found, such as the metabolic regulation of the human body temperature through the evaporation of sweat from the skin, the use of cooling towers or evaporative condensers, the cooling of pools by the evaporation of the water, etc. Furthermore, it was the most widespread method to cool the environment in ancient years, before developing the principles of refrigeration by mechanical compression or absorption. It is important to note which are the historical background and the development of this technology till nowadays.

Originally, this process was firstly applied by humankind in Near East, where the dry and hot climate was favorable to its application. Thus, in paintings from Ancient Egypt (2500 BC) it can be seen how slaves fanned big vessels filled with water, which were porous enough to permit this water to pass through the ceramic wall and maintain the surface humid, evaporating into the air (Bowen, 1981). Other paintings from Rome, founded in a wall from Herculano (70 AD), show a big Wessel made of leather used to cool the drinking water making use of this process. Similarly, the Persian and American Indians tents were maintained humid to be cooled. Other similar applications of the evaporative cooling are used nowadays, like the water bottles of the soldiers covered with wet cloth; or the drinking jugs, which provide drinking water at a temperature below that of the environment. Moreover, old buildings from Iran were commonly cooled by this process, as they were partially built underground to avoid solar radiation, while the upper terraces were provided with pools of water cooled in a kind of cooling towers.

During Middle Age, the Islam spreads this technology all throughout the Occidental countries, and evaporative cooling systems start being used in Mediterranean areas. Leonardo da Vinci probably built the first mechanical air-cooler made of a hollow wheel through which the air was conducted, keeping in contact with a water curtain that fell into different chambers, cooling and purifying the air. The system included wood valves to control it, and it was designed to cool the rooms of his boss' wife (Shakerin, 2000). The first rigorous analysis of the direct and indirect evaporative systems, considering both the advantages and disadvantages and indicating and establishing some basis about their design, was developed by Dr. John R Watt, who worked for the Research Laboratory of the US Navy. He built and studied four prototypes of plate evaporative coolers, one of them constituted of two stages; as well as a cooling tower and coil, determining their efficiency and cooling capacity (Watt, 1986). Currently, the work developed by Dr. Donald Pescod gathers different studies about plate evaporative coolers, being the pioneers in using plastic materials for the plates, and in creating artificial turbulences to minimize the stillness of the air film, reaching really high heat-transfer areas in compact distributions (Pescod, 1974). As the main resistance to heat-transfer can be found in the air on the dry face of the system, the advantage of the higher thermal conductance of metals than that of plastics is negligible. Moreover, plastic avoids corrosion and is adequate to resist the high pressure differences characteristic of this kind of devices. In the 80's, the interest in these systems increases considerable, as probes the high number of articles and communications in scientific journals, developing different applications of this technology like the recovering of the energy associated to the return air stream from the cooled rooms.

## THEORY ON EVAPORATIVE COOLING

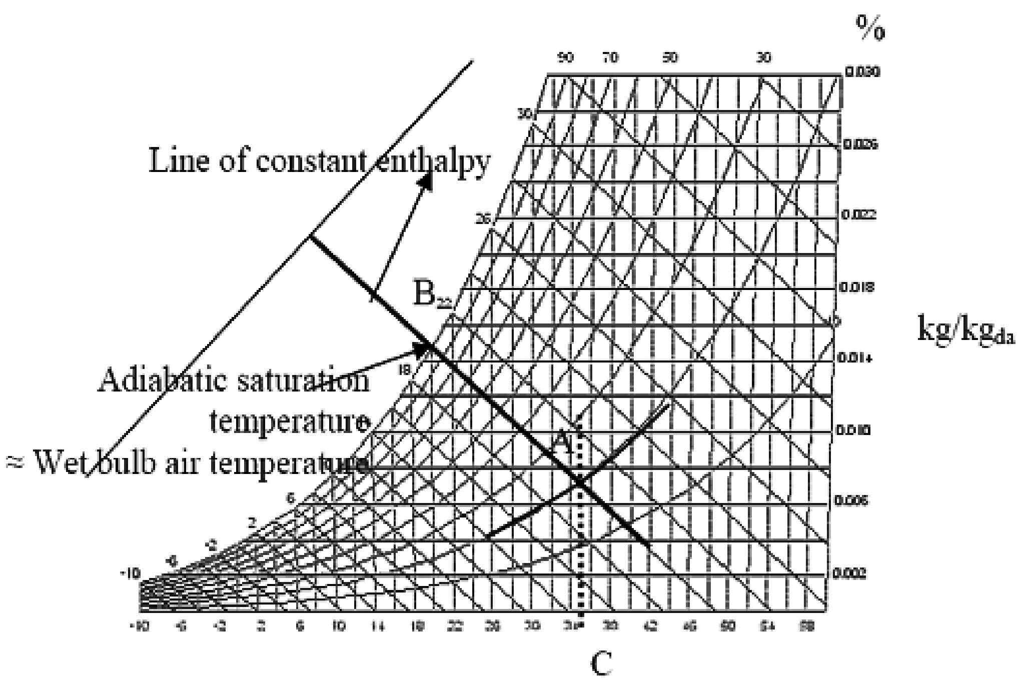
Evaporative cooling is a process of heat and mass transfer based on the transformation of sensible heat into latent heat. The non-saturated air reduces its temperature, providing the sensible heat that transforms into latent heat to evaporate the water. If the process develops in ideal adiabatic conditions, the dry bulb air temperature decreases as this transformation develops, increasing its humidity. This heat exchange continues until the air reaches its saturated state, when the air and water temperature reach the same value, called "adiabatic saturation temperature", being the process known as "adiabatic saturation". To define this temperature we can suppose a long adiabatic tunnel, in which the humid air is introduced in certain conditions, while water is sprayed inside the tunnel and then recirculated, in such a way that the air becomes saturated.

In practice water usually gains some external sensible loads in the tank, pumps and pipes. Moreover, the temperature of the water supplied to support the evaporated part and purges, is not necessarily the adiabatic saturation temperature of inlet air. Thus, in an evaporative cooling process the concept of "adiabatic saturation" is only the theoretical limit up to which water or air involved could be ideally cooled. When the water temperature is considerably over the adiabatic saturation temperature of air, the process is similar to the one characteristic of a cooling tower, where both air and water are cooled simultaneously. In the direct evaporative coolers, such as the ones called "spray in air stream system", water can be heated by the pump or by gains from non-insulated pipes. When it comes into contact with the air, both provide sensible heat and are cooled when it transforms into latent heat, as water evaporates removing heat from the environment to permit the phase change from liquid to vapor, humidifying the air. The majority of the systems of direct spray in air stream use non-recirculated water, as it permits reducing corrosion and incrustations. However, in these systems it should always be prevented the generation of aerosols, and usually incorporates an ultraviolet radiation system . There are limits to the cooling achieved by adiabatic saturation. The amount of sensible heat removed cannot exceed that of the latent heat necessary to saturate the air. The cooling possibilities thus depend inversely on the air humidity. Consequently, when relative air humidity is very high, this process is not very effective. The theoretical and real processes of evaporative cooling are introduced following.

## THEORETICAL EVAPORATIVE COOLING PROCESS

The study of the psychrometric diagram lead to a better understanding of the processes analysed. As pointed before, the theoretical process is adiabatic, and is performed following the constant enthalpy line. The air is adiabatically humidified when coming into contact with water, which is recirculated to maintain its temperature at the adiabatic saturation temperature of inlet air. Because the sensible heat load is transferred to the water surface and transformed into evaporation latent heat, the dry bulb air temperature diminishes, while this loose of sensible heat is simultaneously compensated for the vapor absorption, increasing its absolute humidity. The process develops following a path in the psychrometric diagram that starts in the point of the inlet air conditions, and follows the line of constant enthalpy towards the up left of the diagram (Figure 1). If air reaches saturation (point B), the maximum cooling of the air will be achieved. The figure below shows a theoretical adiabatic saturation cycle of the air at high temperature (35 °C) and low humidity (20%) to describe which would be the theoretical cooling level that would be achieved in an ideal adiabatic saturation process. It can be noticed that the maximum temperature that can be achieved, if water recirculated is at the saturation temperature, is 20 °C.

**Figure 1: Theoretical Evaporative Cooling Process**



## CONVENTIONAL EVAPORATIVE COOLING SYSTEMS

The evaporative cooling can be achieved by direct, indirect systems, or combining these two types in various stages (mixed systems) (ASHRAE Handbook, 2000).

### Direct Evaporative Cooling Systems

In direct systems, water evaporates directly in the air stream, producing an adiabatic process of heat exchange in which the air dry bulb temperature decreases as its humidity increases. Thus, the amount of heat transferred from the air to the water is the same as the one employed in the evaporation of the water (Figure 2).

### Indirect Evaporative Cooling Systems

In the case of indirect evaporative cooling, water evaporates in a secondary air stream which exchanges sensible heat with the

**Figure 2: Direct Evaporative Cooler**

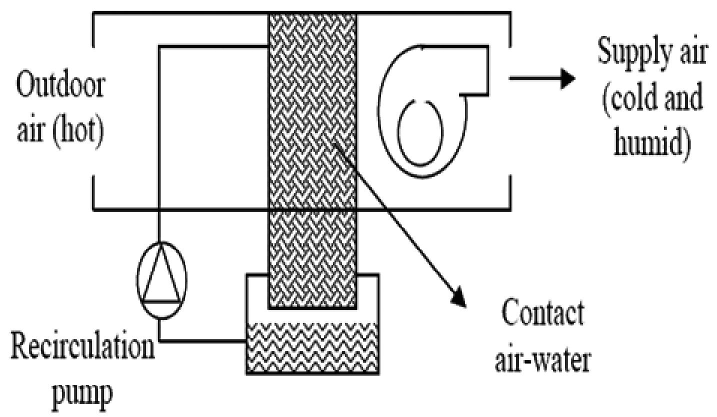
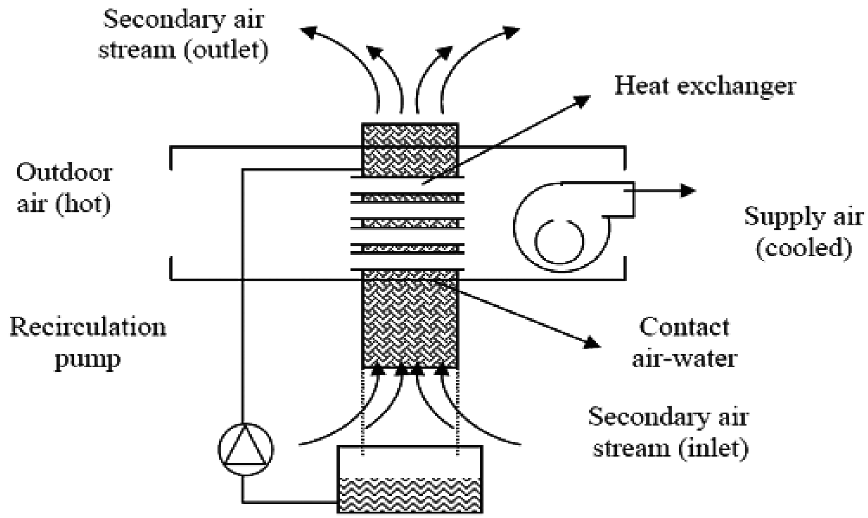



**Figure 3: Indirect Evaporative Cooler**



primary one in a heat exchanger. In this way, the outdoor air stream is cooled when keeping into contact with the surface through which the heat exchange is produced, without modifying its absolute humidity; whereas at the other side of this surface the secondary air stream is being evaporative cooled. Thus, this process is called indirect and is mainly used in those applications where no humidity addition is allowed in the supply air, as well as no risks of contamination, as no mass exchange is permitted between the two air streams (Figure 3).

Among this group of systems there are devices made of either tubular or plate heat-exchangers.

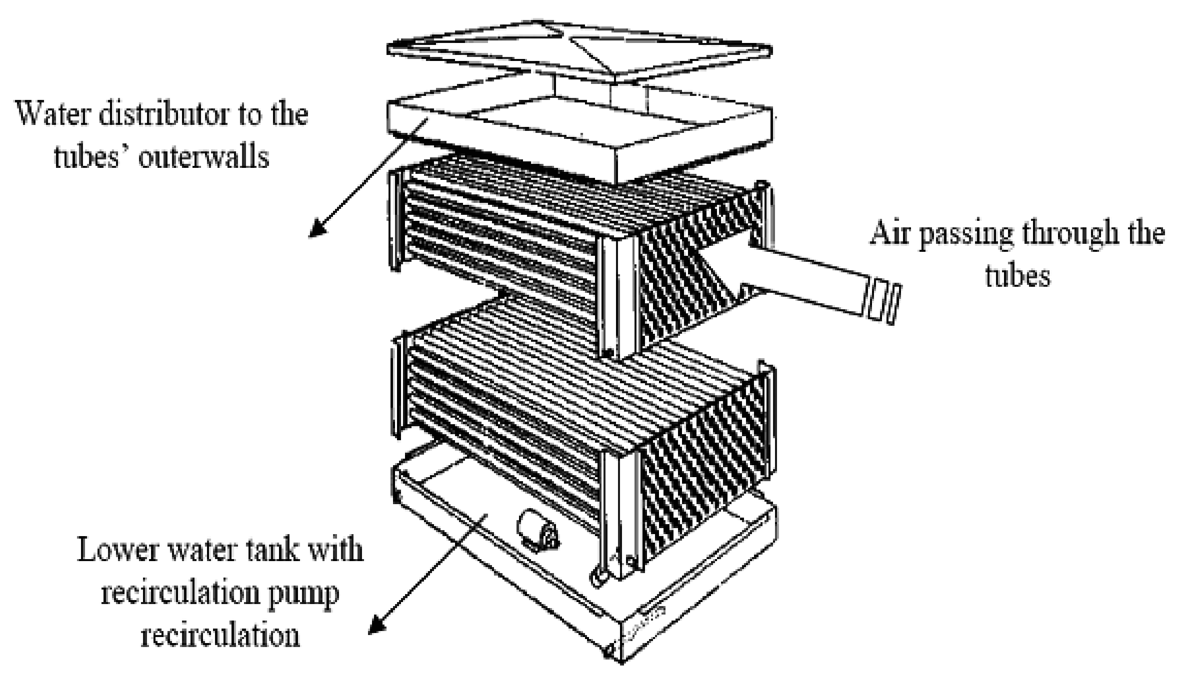
### Indirect System with Tubular Heat-Exchanger

The first reference to this kind of system comes from 1908, from a patent of a German inventor called Elfert. Subsequently, models made of a window air cooler have been developed, which permitted obtaining outdoor air that passed inside a bank of fine horizontal tubes with the aid of a fan, while water was sprayed on the outer walls. More modern designs of these systems used plastic tubes that resisted corrosion better. Figure 4 shows the operation configuration of this kind of devices.

### Indirect System with a Plate Heat-Exchanger

This is undoubtedly the most used indirect evaporative system. The first reference known to this system comes from 1934, and that design suggested two stages. In the first stage return air is cooled in two spray humidifiers (direct evaporative cooling). Afterwards, this air is used in a plate heat-exchanger to cool outdoor air which will be supplied into the

**Figure 4: Tubular Indirect Evaporative Cooler**

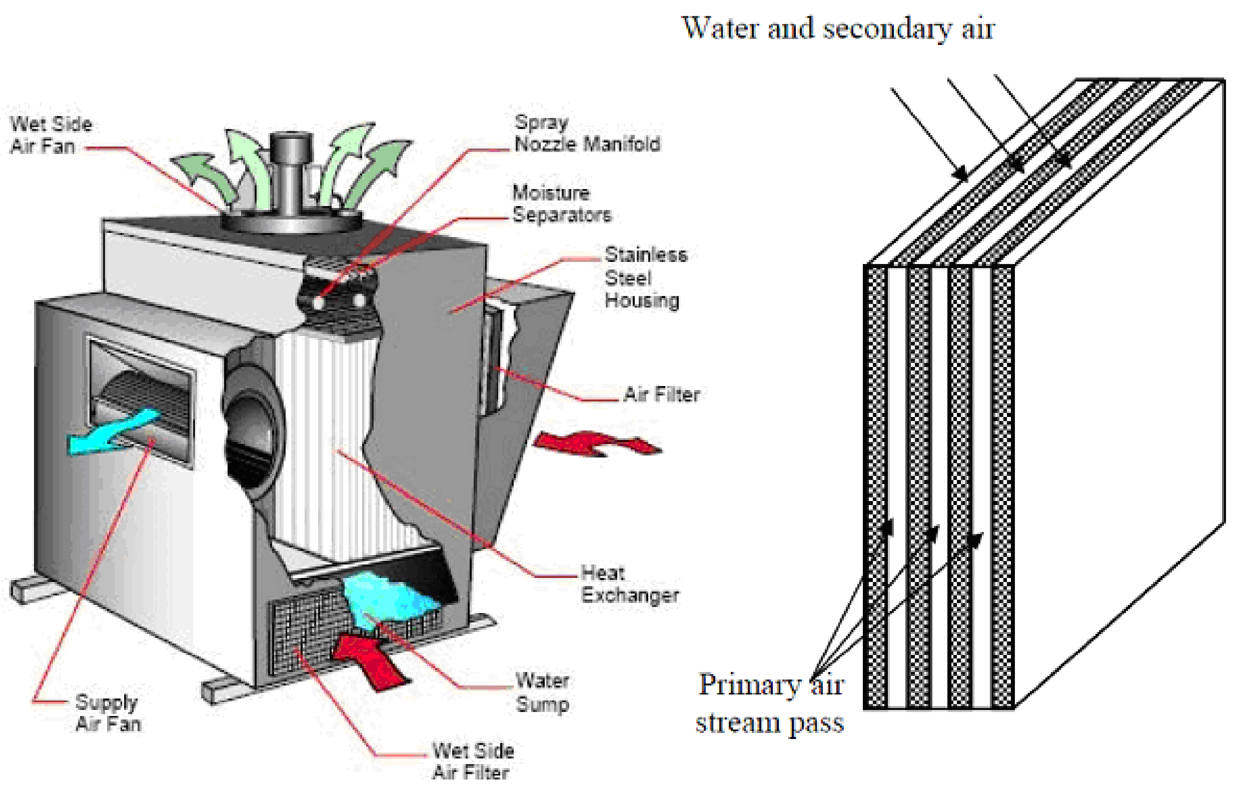


cooled room. Humid air is thrown outdoors. One advantage of this system is that water does not take into contact with the exchange surface, thus not originating incrustations. However, these are really large devices, and heat-exchange between gas mediums requires great areas of transference, so they are not used.

## ADVANTAGES AND DISADVANTAGES

The main advantages of evaporative coolers are their low cost and high effectiveness, permitting a wide range of applications and versatility in the buildings, dwellings, commercial and industrial sectors. They can be specially applied in dry and hot climates, as the minimum cooling temperature for the air depend on its the wet bulb temperature. Evaporative air coolers which are used for air-conditioning in hot and dry climates, have considerably low energy consumption compared to refrigerated systems. Because they do not need any refrigerant, Evaporative air coolers have another important advantage over refrigerated systems which are associated with the ozone layer depletion problem. However, disadvantage is the water consumption associated to the operation of these systems, which is a scarce resource in dry and hot climates, where these systems best work. However, the reduction in electric consumption implies compensation in the global amount of water consumed. This is due to the fact that conventional power plants with an average performance of 40% require removing the remaining 60% heat in a cooling

**Figure 5: Configuration of the Plate Indirect Evaporative Cooler**



tower. Thus, the electric energy used in conventional systems also implies great water consumption (ASHRAE Standard Project Committee SPC 133, 1997; and ASHRAE Standard Project Committee SPC 143, 1997).

## CONCLUSION

These systems can fill the gap between direct evaporative cooling systems and mechanical vapor compression systems as an energy efficient and environmentally clean alternate as it does not make use of any refrigerant. The places where these systems result to be more effective are those characterized by dry and hot climates. However, evaporative cooling systems in a recovering configuration can be applied in whatever climate, as they take advantage of stuffed exhaust air from conditioned rooms, whose conditions are close to those of comfort, to cool the water used in the evaporative process.

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