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Solar Two Stages Evaporative Air Cooler

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Résumé : les systèmes de climatisation basés sur la réfrigération mécanique sont actuellement remis en cause pour deux causes principales : 1) l'énergie consommée, 2) fluides frigorigènes utilisés. L'énergie consommée des systèmes de climatisation provient essentiellement de centrales électriques utilisant des combustibles fossiles ayant un impact direct sur notre environnement. Les fluides frigorigènes utilisés ont un potentiel d'appauvrissement de la couche d'ozone (ODP), et un potentiel de réchauffement climatique (GWP). Les systèmes de rafraichissement évaporatifs à un seul étage utilisent 100% d'air extérieur, ce qui est bien pour les besoin de ventilation, mais des provisions doivent être faites pour extraire tout l'air extérieur admis pour éviter la saturation de l'air dans les locaux conditionnés. Avec les systèmes de rafraichissement évaporatifs à deux étages, l'air est pré-refroidi dans un échangeur de chaleur utilisant de l'eau avant de passer dans le système de rafraichissement évaporatif. Cette combinaison nous permet d'éviter la saturation prématurée de l'air dans les locaux conditionnés. Dans cet article on va présenter un système de rafraichissement évaporatif à deux étages et les différentes possibilités de son application. La consommation électrique de ce système étant relativement faible, l'utilisation de l'énergie solaire d'origine photovoltaïque peut être facilement utilisée**.**

Mots clés :

Energie solaire, Système de rafraichissement évaporatif à deux étages, Dimensionnement.

Abstract

Air conditioning systems based on mechanical refrigeration are being questioned for two major raisons,

- Energy consumption and Refrigerant used.

The energy consumed by air conditioning systems come basically from power plant using natural gas, which has direct impact on the environment. The refrigerants used in these systems have a varying degree of global warming and ozone depletion potentials, which also have a direct impact on our environment.

Evaporative cooler are an excellent alternative for air conditioning systems based on mechanical refrigeration when the weather conditions are right for the application (hot and dry climate), which is basically the two third (2/3) of the country. Also, well designed evaporative coolers have very low energy consumption, and the fluids used have no impact whatsoever on our environment. Single stage evaporative cooler uses hundred percent (100%) outside air, which is excellent for ventilation requirement, but provisions have to be made in order to evacuate all the incoming outside air in order to avoid the early saturation of the air in the conditioned space. In the two stage evaporative cooler, the incoming outside air is first cooled in a heat exchanger and then passed to the evaporative cooler for final treatment. By doing this, we will avoid the early saturation of the air in the conditioned space and will improve the overall efficiency of the system.

In this article, we will present a solar two stage evaporative cooler and investigate the various possibilities of its uses in domestic, industrial, and agricultural applications.

1. Introduction

Evaporative cooling equipment have known a very rapid development in a recent years. From domestic to large scale industrial, commercial and agricultural application recent market analysis shows that the demand for evaporative cooling equipment keep growing rapidly. This favorable situation is explained by the facts that, reserves have been emitted concerning air conditioning equipments based on vapor compression refrigeration.
The refrigerant being used have large Ozone Depletion Potential and a large Global Warming Potential. The electrical energy consumed comes basically from power stations using natural gas and generate combustion products with large Global Warming Potential.

Evaporative cooling equipments have been around for centuries. They are simple, effective, economical, and can provide very good comfort and health conditions if the climate is favorable .The sizing procedure is straightforward and depend mainly on the number of air change per hour (NA/Hr) of the occupied space. The operating principle is very simple (fig.1).

Water is continuously circulated with a small centrifugal pump. The media pad is kept permanently saturated with water. Dry and warm air is drawn trough the wetted media pad. The water eventually reaches and maintains a temperature equal to the wet bulb temperature of the incoming air. After, this state of equilibrium has been reached , water temperature will lower the dry bulb temperature of the incoming air more or less according to the efficiency of the evaporative cooler.

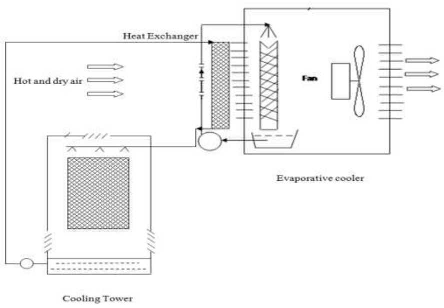

Figure 1 : Two stages evaporative cooler

2. Principe of operation

Air is pre-cooled in a cross-flow heat exchanger to a temperature below the prevailing dry bulb temperature, using water from a cooling tower. This water is cooled anywhere close to the wet bulb temperature of the incoming air depending on the efficiency of the cooling tower and the prevailing climatic conditions.

The evaporative pad is kept saturated with water. As air flows through the evaporative pad, it loses sensible heat; which causes its dry bulb temperature to drop, and gains latent heat which causes its humidity ratio to rise (fig.2 , fig.3 and fig.4)

A note of precaution should be made: For this type of application 100% outside air is brought into the occupied space, so provision should be made to allow the same amount to escape, in order to avoid air saturation.

Humidifying efficiency = actual dry bulb change / theoretical dry bulb change

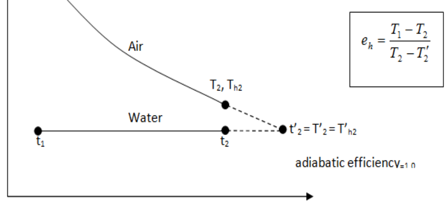

Figure 2 : Temperature Profile for evaporative cooling process.

It is important to note that the efficiency of the evaporative cooler depend on several factors, as the evaporative pad thickness, the air velocity, the dry and wet bulb temperature of the outside air, etc..

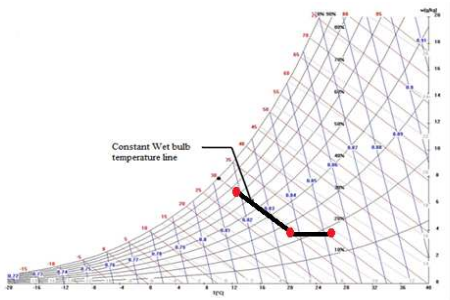

Figure 3: Psychrometric chart representation for two stage evaporative air cooling process.

3. Method to evaluate evaporative cooling systems

The Feasibility index (FI) method is a fast method used to verify the viability of using evaporative cooling equipment of air conditioning for human thermal comfort and their application to several cities [7], and is defined by:

$$FI = Twb - \Delta T \qquad (1)$$

This index decreases as the difference between dry bulb and wet bulb temperature increases, i.e. as air relative humidity decreases. It shows that, the smaller FI is, more efficient the evaporative cooling will be. Thus, this number indicates the evaporative cooling potential to give thermal comfort. It is recommend that indices that are under or equal to 10 indicate a comfort cooling, indices between 11 and 16 indicate lenitive cooling (relief) and indices above 16 classify the place as not recommended for use evaporative cooling systems.

From these limits it is possible to conclude that, to reach a comfort recommended performance index, a wet bulb depression from, at least, 12ºC, is needed. It corresponds, e.g. to a DBT of 34ºC with WBT of 22ºC, characterizing a region with relative humidity of approximately 35%.

4. Theoretical study of direct evaporative air cooler

Evaporative cooling involves heat and mass transfer, which occurs when water and the unsaturated air water mixture of the incoming air are in contact. This transfer is a function of the differences in temperatures and vapor pressures between the air and water. Heat and mass transfer are both operative in the evaporative cooler because heat transfer from the air to the water evaporates water, and the water evaporating into the air constitutes mass transfer. Heat inflow can be described as either latent or sensible heat. Whichever term is used depends on the effect. If the effect is only to raise or lower temperature, it is sensible heat. Latent heat, on the other hand, produces a change of state, e.g., freezing, melting, condensing, or vaporizing. In evaporative cooling, sensible heat from the air is transferred to the water, becoming latent heat as the water evaporates. The water vapor becomes part of the air and carries the latent heat with it. The air dry-bulb temperature (DBT) is decreased because it gives up sensible heat. The air wet-bulb temperature (WBT) is not affected by the absorption of latent heat in the water vapor because the water vapor enters the air at the air wet-bulb temperature. Theoretically, the incoming air and the water in the evaporative cooler may be considered an isolated system. Because no heat is added to or removed from the system, the process of exchanging the sensible heat of the air for latent heat of evaporation from the water is adiabatic. Evaporative cooler performance, therefore, is based on the concept of an adiabatic process.

The minimum temperature that can be reached is the wet bulb temperature of the incoming air. Wet porous materials or pads provide a large water surface in which the air is moistened and the pad is wetted by dripping water. Typical variation of air dry bulb, wet bulb and dew point temperatures is illustrated on figure 4.

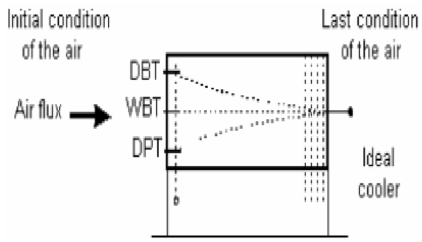

Figure 4 : Typical variation of air dry bulb, wet bulb and dew point temperatures

The direct evaporative cooling process (see figure 3) works essentially with the conversion of sensible heat in latent heat. The surrounding ambient air is cooled by evaporation of the water from the wet surface of the panel to the air. The addition of water vapor to the air increases its latent heat and relative humidity. If it the process is adiabatic, this increase of the latent heat is compensated by a reduction of the sensible heat and consequent reduction of the dry bulb temperature of air (Fig. 2).

The direct evaporative panel can basically be considered as a heat exchanger in cross flow (Castro and Pimenta, 2003). Then, applying an analysis based in classical heat transfer theory, the LMTD method (Log Mean Difference Temperature) can be used. So, the rate of heat transfer from air to water in the wet panel surface, $\dot{q}$, is given by:

$$\dot{q} = h_H . A_S . \Delta T_{LM} \qquad (2)$$

Where h_H represents the heat transfer coefficient, A_S is the wet surface area of the panel and ΔT_{LM} the log mean temperature difference, given by

$$\Delta T_{LM} = \frac{(T_2 - T_1)}{\ln(T_2 - T_{wb})/(T_1 - T_{wb})} \qquad (3)$$

where T_1, T_2 and T_{wb} are the dry bulb temperatures at the evaporative panel inlet, outlet and the wet bulb temperature of surroundings ambient air.

Substituting Eq. (3) into Eq. (2) and regrouping terms follows that,

$$1 - \frac{T_1 - T_2}{T_1 - T_{wb}} = \exp\left(-\frac{h_H . A_S . (T_1 - T_2)}{\dot{q}}\right) \qquad (4)$$

where the terms $(T_1-T_2)/(T_1-T_{wb})$ is defined as the panel effectiveness ε , i.e.,

$$\varepsilon = \frac{T_1 - T_2}{T_1 - T_{wb}} \qquad (5)$$

From Eq.(4) the effectiveness of the evaporative panel can also be expressed as,

$$\varepsilon = 1 - \exp\left(-\frac{h_H . A_S . (T_1 - T_2)}{\dot{q}}\right) \qquad (6)$$

And then,

$$\varepsilon = 1 - \exp\left(-\frac{h_H . A_S}{\dot{m_a} . cp_a}\right) \qquad (7)$$

This equation shows that an effectiveness of 100% corresponds to air leaving the equipment at the wet bulb temperature of entrance. This requires a combination of large area of heat transfer and a high heat transfer coefficient and low mass flow. Also it is observed that the effectiveness is constant if the mass flow is constant, since it controls directly and indirectly the value of the parameters on the equation.

In analyzing the effectiveness of a direct cooling system, the key point is evaluating the value of hH As. For a rigid cellulose evaporative media, effective evaporative surface area per cubic meter of media could be determined. Therefore according to the size of pad, wetted area in the pad of the equipment would be obtained (Camargo et al. [7]).

Dowdy and Karabash [15] presented a correlation to determine the convective heat transfer coefficient in a rigid cellulose paper evaporative media:

$$Nu = 0.1 . \left(\frac{L_e}{L}\right)^{0.12} . Re^{0.8} . Pr^{1/3} \qquad (8)$$

Nu: Nusselt number
Re: Reynolds number
Pr: Prandlt number

In above equation Le is characteristic length and defined by:

$$L_e = \frac{V}{A} \qquad (9)$$

Where:
A: area of the heat transfer surface; total wetted surface area (m^2)
V: volume occupied by the evaporative pad (m^3)
L: pad thickness (m)

Then, the air temperature leaving the evaporative panel (T_2) can be calculated from Eq.(5) as,

$$T_2 = T_{db} - \varepsilon.(T_{dw} - T_{wb}) \qquad (10)$$

5. Rating of an evaporative air cooler

The air change method is used to design an evaporative air cooler. It is based on air change rate (air changes per hour) which is given from codes and standards for specific applications (some common types of rooms and buildings). Note that in many cases local regulations and codes will govern the ventilation requirements.

Once the air change rate is determinate, the air flow rate is calculated from this equation:

$$m = V.ACR/3600 \qquad (11)$$

And water consumption is calculated by this equation:

$$WC = m.(x2 - x1) \qquad (12)$$

x1 and x2 can be taken from psychometric chart.

6. Energy Efficiency Ratio (EER):

The Energy efficiency ratio (EER) was developed by the industry to evaluate the rate of energy consumption for air conditioning units. The EER represents a measure for rating air conditioning units. The energy efficiency ratio EER is defined as the net thermal energy removed from air for cooling purposes per watt of energy expended. That is

$$EER = \frac{Q}{W} \qquad (13)$$

Where:

$$Q = \dot{m}_a . cp_a . \left(T_1 - \left(T_{db} - \varepsilon(T_{db} - T_{wb})\right)\right) \qquad (14)$$

Q: cooling load (W)
cp_a: specific heat of the air
$\dot{m}_a$: Mass flow rate of the air
where W is the input electrical power in W of the exhaust fan and water pump.

The energy consumed is relatively low compared to the energy consumed by an air conditioning equipment of equivalent cooling capacity, making the use of solar photovoltaic energy an attractive and economical choice.

7. Discussion and conclusion

Evaporative cooling equipments work well in the hot and arid southern regions, which constitute practically the two third of the country. They have no impact whatsoever on the environment. The water consumption is not very excessive (however this could be a problem in certain places). Energy consumption is much less than in classical air conditioning equipments. Possible application in greenhouse, poultry and cattle growing buildings. Considerable improvement in the cooling efficiency can be obtained with the use of two stage evaporative cooler. In isolated area, the use of solar photovoltaic energy is a very attractive, economic, and environmentally friendly choice.

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