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A review on desiccant based evaporative cooling systems

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ABSTRACT

The air conditioner should control the building sensible and latent load properly in order to provide the indoor comfort conditions. The conventional mechanical vapor compression system usually controls the latent load by the process of condensation of water vapor in which air is cooled below its dew point temperature and then reheated again up to the required supply conditions. The conditions where latent load is dominant these two processes i.e. overcooling and then reheating again will increase the consumption of electrical energy and emission of CO_2 remarkably. To avoid this wastage of primary energy and emission of harmful gases, desiccant based evaporative cooling system is a good alternative to traditional air conditioning system which is cost effective as well as environment friendly. It can be driven by thermal energy which makes a good use of solar energy which is free as well as clean. In this paper, a review of desiccant based evaporative cooling systems has been presented. The present study is undertaken from variety of aspects including background and need of alternative cooling systems, concept of conventional and desiccant based evaporative coolers, system configurations, operational modes, as well as current status of the desiccant based evaporative cooling technology. The review work indicated that the technology of desiccant based evaporative cooler has a great potential of providing human thermal comfort conditions in hot and humid climatic conditions at the expense of less primary resources of energy as compared to conventional cooling systems. Some modified and modern evaporative coolers have also been introduced in this paper.

Contents

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Nomenclature

C_{pa}	specific heat of air (kJ kg^{-1} °C^{-1}).
h_1	specific enthalpy of process air at inlet of evaporative cooler (kJ kg^{-1}).
h_2	specific enthalpies of process air at outlet of evaporative cooler (kJ kg^{-1}).
h_{v1}	specific enthalpies of water vapor at inlet of evaporative cooler (kJ kg^{-1}).
h_{v2}	specific enthalpies of water vapor at outlet of evaporative cooler (kJ kg^{-1}).
h_{fg}	latent heat of vaporization (kJ kg^{-1}).
$\dot{m}_1$	mass flow rate of process air (kg s^{-1}).
$\dot{m}_{v1}$	mass flow rate of water vapor at inlet of evaporative cooler (kg s^{-1}).
$\dot{m}_{v2}$	mass flow rate of water vapor at outlet of evaporative cooler (kg s^{-1}).
$\dot{m}_w$	evaporation rate of water (kg s^{-1}).
$\dot{Q}$	sensible cooling capacity (kW).
$\dot{Q}_t$	total cooling capacity (kW).
T	dry bulb temperature of air (°C).
T_w	wet bulb temperatures of air (°C).
T_{dp}	dew point temperature of air (°C).
$\dot{V}$	volume flow rate of delivered air (m^3 s^{-1}).
W_{in}	energy input (kW).

Greek symbols

ε	effectiveness (dimensionless)
ω	humidity ratio of the air (kg$_v$ kg$_a^{-1}$)
ρ_a	density of air (kg m^{-3})

Subscripts

1, 2, 3…	state points
o	outlet
i	inlet

1. Introduction

In order to provide the human comfort indoor conditions, the cooling requirements should not be mentioned in terms of sensible cooling capacity (temperature control) only but latent cooling (control of humidity) should also be included especially for hot and humid outdoor conditions. The range of human comfort conditions and basic requirements for the human comfort need to be provided by the air conditioning system are illustrated in Fig. 1 [1] and Fig. 2 [2] respectively.

The two components of the load are described by the sensible heat ratio which is the ratio between sensible load to the total load, that is, sensible+latent. Smaller the value of sensible heat ratio larger the value of latent cooling load:

$$\text{Sensible heat ratio} = \frac{\text{Sensible heat}}{\text{Sensible heat} + \text{Latent heat}} \quad (1)$$

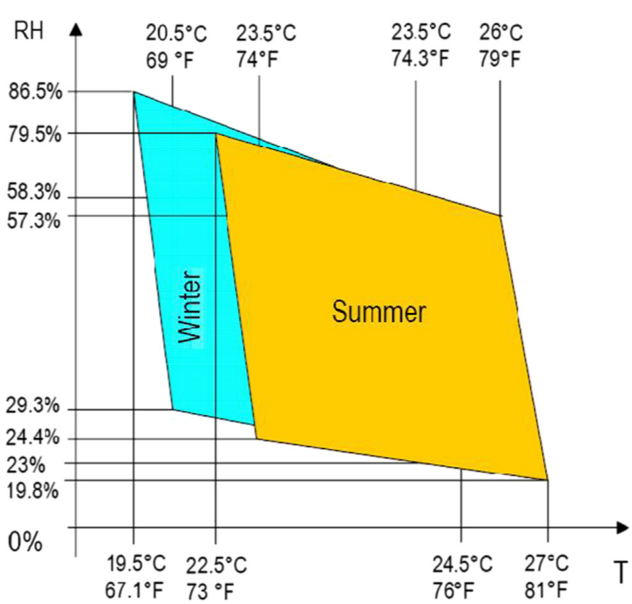

Fig. 1. Thermal comfort zone according ASHRAE55 [1].

The value of sensible heat ratio is about 0.75 for the commonly used conventional vapor compression air-conditioning systems which means that 75% capacity of the system is used to control the sensible load and the remaining 25% for the latent load. So, the conventional systems can provide the comfort conditions only when sensible heat ratio is greater than 0.75 [3]. The value of designed sensible heat ratio can be significantly less than 0.75 for the hot and humid climates and which cannot be achieved using a conventional air conditioning system and hence thermal comfort conditions cannot be achieved. Second, the condensate coming out due to the overcooling, can evaporate back to the conditioned space which may result in increased humidity level in the comfort zone [4]. These problems of conventional air conditioning systems can be addressed using a technology called desiccant based evaporative cooling. This technology is a combination of a desiccant dehumidifier and indirect evaporative cooler. The only energy used in this system is to drive the fans, water pump and to regenerate the desiccant dehumidifier during the regeneration process. This energy can be provided from any low grade thermal energy source such as solar, waste heat, etc. The sensible and latent loads can be controlled separately in this system using a humidistat and thermostat for the control of wet and dry bulb temperatures respectively. This system can operate on wide range of sensible heat ratios because of the decoupling of sensible and latent cooling loads. A comparison between different cooling techniques is presented in Table 1.

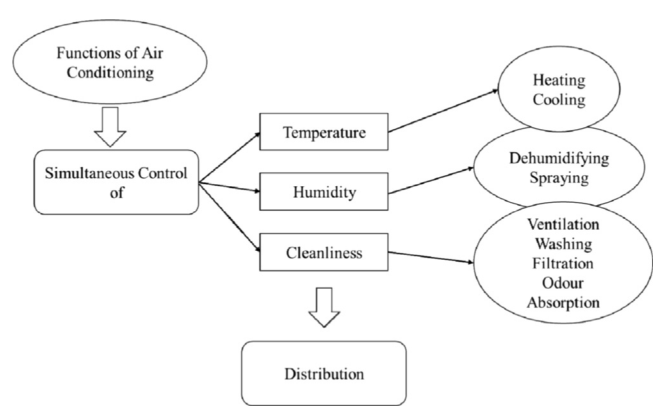

Fig. 2. The functions of air conditioning [2].