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ORIGINAL ARTICLE

Parametric analysis of a combined dew point evaporative-vapour compression based air conditioning system

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Effectiveness;
Cooling load;
Conditioned space

Abstract A dew point evaporative-vapour compression based combined air conditioning system for providing good human comfort conditions at a low cost has been proposed in this paper. The proposed system has been parametrically analysed for a wide range of ambient temperatures and specific humidity under some reasonable assumptions. The proposed system has also been compared from the conventional vapour compression air conditioner on the basis of cooling load on the cooling coil working on 100% fresh air assumption. The saving of cooling load on the coil was found to be maximum with a value of 60.93% at 46 °C and 6 g/kg specific humidity, while it was negative for very high humidity of ambient air, which indicates that proposed system is applicable for dry and moderate humid conditions but not for very humid conditions. The system is working well with an average net monthly power saving of 192.31 kW h for hot and dry conditions and 124.38 kW h for hot and moderate humid conditions. Therefore it could be a better alternative for dry and moderate humid climate with a payback period of 7.2 years.

1. Introduction

Air conditioning through evaporative cooling is one of the good alternatives to conventional vapour compression air conditioning, as these systems generally consume less electric power than conventional vapour compression air conditioning systems. Therefore, these systems help to decrease the peak electricity demand and also contribute to decrease the harmful greenhouse gas emissions. Conventional evaporative cooler reduces the process air temperature: approaching the wet bulb temperature of air.

Direct and indirect are the two conventional types of evaporative cooling systems available of which direct evaporative cooling system has generally higher cooling effectiveness as compared to indirect cooling system. However, direct evaporative cooling system is applicable only to dry climates because it increases the moisture in air as shown in Fig. 1(a), which makes the condition uncomfortable due to increased humidity of air in the humid climate. On the other hand indirect evaporative cooling reduces the temperature of process air without adding the moisture into it as shown in Fig. 1(b). However, it is generally having low cooling effectiveness. Therefore, it

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Nomenclature

h	specific enthalpy of air, kJ/kg
Δh	change in enthalpy, kJ/kg
m_a	mass flow rate of air kg/s
Q	cooling load, kW
Q_r	Cooling rate to the conditioned space, kW
s	second
T	Dry bulb temperature, °C
X	bypass factor of the cooling coil
ϕ	relative humidity, %
ε	effectiveness of evaporative cooler
ω	specific humidity of air, kg/kg of dry air

Subscript

ae	condition of air after evaporative cooler
c	cooling coil
cs	conventional system
dew	dew point
i	inside design condition of conditioned space
in	inlet air
o	outside (ambient) condition
ps	proposed system
s	supply condition of air to the room
wb	wet bulb
wk	working air

Acronyms

ADP	apparatus dew point, °C
ANMPS	average net monthly power saving
CCC	conventional cooling coil
CFM	cubic feet per minute
COP	coefficient of performance
DBT	dry bulb temperature, °C
DEC	direct evaporative cooler
DPC	daily power consumption
DPEC	dew point evaporative cooler
DPT	dew point temperature, °C
IEC	indirect evaporative cooler
kW h	kilo watt hour
MPC	monthly power consumption
MPS	monthly power saving
NMPC	net monthly power consumption
NMPS	net monthly power saving
PC	power consumption
TR	tons of refrigeration
VCR	vapour compression refrigeration
WBT	wet bulb temperature, °C

cannot cool the temperature of process air to the human comfort conditions working alone.

A dew point evaporative cooler is a better substitute for the above as it decreases the process air temperature below its wet bulb temperature without adding moisture, approaching the dew point temperature of the process air. However, in real application where the ambient temperature increases beyond 40 °C and reaches up to 45 °C, the dew point evaporative cooler working alone cannot reduce the ambient temperature to human comfort condition at desired cooling rate. Therefore, conventional vapour compression air conditioner can be used in conjunction with the dew point evaporative cooler, which will change the ambient air to human comfort condition at desired cooling rate by consuming comparatively less electric power: as partial cooling load is shared by the dew point evaporative cooler.

Kim and Jeong [1] studied the energy performance of an indirect and direct evaporative cooler assisted 100% outdoor air system (IDECOAS). Results revealed that the IDECOAS operating in the two-stage mode in the intermediate season shows a 51% energy saving over the conventional variable air valve (VAV) system. However, the proposed system may consume 36% more operating energy than the conventional VAV system during the cooling season due to limited cooling performance of the indirect evaporative cooler (IEC) in hot and humid climate. Jain et al. [2] studied the financial feasibility of a hybrid direct evaporative cooler (DEC) combined with an air conditioning (AC) unit to reduce the annual expenditure on electricity usage (as against standalone AC unit to provide almost similar level of comfort). They considered four different building applications located in four different places of India. The hybrid mode operation is found financially attractive for movie theatres and waiting hall building applications for all the climatic conditions considered in the study.

Delfani et al. [3] investigated the performance of indirect evaporative cooling (IEC) system to pre-cool air for a conventional mechanical cooling system for four different locations of Iran. A combined experimental setup of an IEC unit and a packaged unit air conditioner (PUA) was designed, constructed and tested. The performance and energy reduction capability of combined system have been evaluated through an analytical method for the cooling season. The result reveals that IEC can reduce cooling load up to 75% with 55% reduction in electrical energy consumption of PUA during cooling season. Cui et al. [4] presented a hybrid system that combines indirect evaporative cooler (IEC) system and vapour compression system. The exhaust air from the conditioned room is used as the working air for IEC and outdoor fresh air is used as the product air, as a result of which the IEC unit produces pre-cooled air for vapour compression system. Two types of IEC units, namely a conventional counter flow IEC unit and a novel counter flow IEC unit based on Maisotsenko (M-cycle), have been numerically analysed. Results reveal that the humid outdoor fresh air can be pre-cooled to a temperature below its dew point temperature when the wet bulb temperature of the exhaust air is lower than the dew point temperature of the outdoor air. Wang et al. [5] investigated the Coefficient of Performance (COP)'s augmentation of an air conditioning system using an evaporative cooling condenser. The experimental setup consisted of four major components namely compressor, evaporator, thermal expansion valve, and the condenser. An evaporative cooling unit was located upstream from the condenser. Thermal parameters, such as dry bulb temperature, wet bulb temperature and rela-