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Research Paper

Experimental analysis of an evaporative–vapour compression based combined air conditioning system for required comfort conditions

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HIGHLIGHTS

- An evaporative vapour compression based combined air conditioning system was fabricated and tested.
- System was run in three different modes according to the climatic conditions.
- System performance was studied for wide range of ambient conditions.
- Effects of various operating parameters on system performance were studied in detail.
- Maximum energy saving was found 24% at 43.2 °C and 18.1% relative humidity.

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ABSTRACT

An evaporative–vapour compression based combined air conditioning system for providing required human comfort conditions at comparatively low cost has been presented. The combined system has been experimentally analysed in a particular experimental setup at Bhopal, India for a wide range of ambient conditions in different modes of operation according to the climatic condition. System has also compared from conventional vapour compression air conditioner working at same fresh air ratio (FAR) and air flow rate for similar inside set temperature. Maximum energy saving in the combined system was found 23.8% at 43.3 °C ambient temperature and 18.1% relative humidity, while it was run at no profit–no loss condition for humid climate. The system is working well with an average monthly power saving of 58.5 kW h for moderate hot and dry, and 163.5 kW h for hot and dry conditions. Therefore it could be a better alternative to conventional air conditioning system for dry and humid climate with a payback period of 8.1 years.

1. Introduction

Temperature of surrounding air is increasing by the global warming every year. It is not comfortable to stay inside without a perfect cooling system. Air conditioners are becoming a primary home appliance across the world to change the indoor condition to the human comfort range. The indoor temperature and humidity both equally contributes for good human comfort condition [1]. The cooling coil of the conventional vapour compression air conditioning system acts as cooling and dehumidifying coil, so there is always a decrease in temperature and specific humidity of the air passing through the coil. These air conditioners working in hot and dry climatic conditions produce cold and dry air. Since there is 100% air recirculation in domestic conventional type air conditioners, so this cold and dry air keeps on reducing the moisture content every time while recirculating through the same cooling coil and becomes drier.

There is no provision of adding the moisture (increasing the specific humidity) in the air passing through the coil in the conventional air conditioning system. Since the inside air is recirculated every time through the cooling coil, so it reduces its specific humidity below the human comfort condition range. Human being feels uncomfortable when seating continuously under these dry conditions for long time. Opening the doors and windows to allow some fresh air reduces this condition to some extent. When the human body is exposed under such dry air for many years causes serious health problems related to skin & joint pain in the people of all age groups. The synovial fluid of the joints which act as lubricant begin to dry up due to evaporation. This may allow the bones to rub against each other painfully [2].

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Nomenclature

h	specific enthalpy of air, kJ kg^{-1}
Δh	change in enthalpy, kJ kg^{-1}
$\dot{m}$	mass flow rate, kg s^{-1}
Q	cooling load, kW
s	second
T	dry bulb temperature, °C
$\dot{V}$	volume flow rate, m^3 h^{-1}
ϕ	relative humidity, %
ω	specific humidity of air, g kg^{-1} of dry air

Subscript

a	air
ec	condition of air after evaporative cooler
cc	cooling coil
i	inside design condition of conditioned space
lat	latent
m	condition of air in mixing chamber
o	outside (ambient) condition
s	condition of supplied air to room
sen	sensible
wb	wet bulb

Acronyms

ADP	apparatus dew point, °C
AMES	average monthly energy saving
BPF	bypass factor
CCC	conventional cooling coil
COP	coefficient of performance
CRR	condensate removal rate, kg h^{-1}
DBT	dry bulb temperature, °C
DEC	daily energy consumption, kW h
DPT	dew point temperature, °C
DPEC	dew point evaporative cooler
FAR	fresh air ratio, (%)
HEC	hourly energy consumption, kW h
IEC	indirect evaporative cooler
INR	Indian Rupee
kW h	Kilo Watt Hour
MEC	monthly energy consumption, kW h
MES	monthly energy saving, kW h
TR	tons of refrigeration
VCC	vapour compression cooling

The above problems can simply be reduced by increasing the indoor relative humidity by using the direct evaporative cooler [3], but the direct evaporative cooler working alone cannot decrease the inside temperature to human comfort condition for the hot Indian climate. Hence, conventional vapour compression air conditioning system should be used along with the direct evaporative cooler which can reduce the temperature to human comfort condition.

Kim et al. [4] 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 volume (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. Delfania et al. [5] investigated the performance of indirect evaporative cooling (IEC) system for pre cooling the air supplied to a conventional mechanical cooling system for four different locations of Iran. The result shows that IEC can reduce cooling load up to 75% with 55% reduction in electrical power consumption during cooling season.

Chauhan and Rajput [6] proposed an evaporative–vapour compression based combined air conditioning system for providing good human comfort conditions at a low cost working under hot and dry climate. The saving of cooling load on the coil was found maximum with a value of 64.2% in the month of March and it was found minimum for the month of May with a value of 27.4%. The proposed system worked well for hot and dry climate with a net power saving of 646.8 kW h from March to May for a small capacity application. Chauhan and Rajput [7] proposed the parametric analysis of a dew point evaporative–vapour compression based combined air conditioning system for providing better human comfort conditions at a low cost. The results indicates that the system is working well with an average net monthly power saving of 192.3 kW h for hot and dry conditions and 124.4 kW h for hot and moderate humid conditions.

Cui et al. [8] presented a hybrid system that combines indirect evaporative cooler (IEC) system and vapour compression system. 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. Jain et al. [9] 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 compared to AC unit operating alone to provide similar level of comfort). Wanga et al. [10] investigated the Coefficient of Performance (COP)'s augmentation of an air conditioning system using an evaporative cooling condenser. Thermal parameters, such as, dry bulb temperature, wet bulb temperature, and relative humidity was measured to find out the effect of indirect evaporative cooling on the COP of the system. Riangvilaikul and Kumar [11] studied a novel dew point evaporative cooling system for sensible cooling of the ventilation air for air conditioning application. The key result shows that wet bulb effectiveness spanned between 92% and 114% and the dew point effectiveness between 58% and 84%.

Bruno [12] conducted an experiment which takes the advantage of evaporative cooling to reduce the temperature of air without the addition of moisture. Wu et al. [13] theoretically analyzed the heat and mass transfer between air and water film in the direct evaporative cooler. Cooling efficiency correlation was also validated by the experimental results of a direct evaporative cooler. Heidarinejad et al. [14] presented the study on a hybrid system of nocturnal radiative cooling, cooling coil, and direct evaporative cooling. The results reveal that overall effectiveness of hybrid system is greater than 100%. Riangvilaikul and Kumar [15] presented the theoretical performance of a novel dew point evaporative cooling system operating under various inlet air conditions. The results predicted by the model using numerical method have been validated with the experimental findings. Anisimov and Pandelidis [16] developed a numerical model based on the modified e–NTU (number of transfer units) method to perform thermal calculations of the indirect evaporative cooling process. The model was also validated against experimental data available from literature.

Heidarinejad et al. [17] experimentally investigated the cooling performance of two-stage indirect/direct evaporative cooling system in the different simulated climatic conditions. Results reveal that the effectiveness of IEC stage varies over a range of 55–61%, while the effectiveness of IEC/DEC unit varies over a range of