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Psychrometric Analysis of Indirect Evaporative Cooling Based Dedicated Outdoor Air System for Indian Cities with Different Climatic Conditions

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Abstract : This paper presents analysis of an indirect evaporative cooling based dedicated outdoor air system, DOAS based on cooling and desiccant dehumidification of fresh outdoor air by indirect evaporative cooling of exhaust air. The system is examined for its suitability for application in Indian cities with different climate conditions. Psychrometric analysis for this system is performed for various climate conditions of different Indian Cities: Warm and humid (Mumbai), Composite (New Delhi), Moderate (Bangalore) and Hot and dry (Ahmedabad). The DOAS configuration was found suitable for warm and humid climate which have fairly high relative humidity values throughout the year.

Keywords: Dedicated outdoor air system, Pyschrometric analysis, evaporative cooling, humidification, fresh air, exhaust air

Introduction

Dedicated outdoor air systems usually are designed to provide total ventilation air required for the conditioned space. These systems are designed to take care of all or part of latent load and part of the sensible load. Any other parallel cooling equipment balances remaining sensible/latent load requirement. There may not be any mixing of outside air with return air as in conventional all air VAV systems.

Dedicated outdoor air systems consist of appropriate design of, deep cooling coil, desiccant wheels, enthalpy wheel and sensible heat exchangers. Enthalpy wheels and sensible heat exchangers enhance energy efficiency through exhaust heat and energy recovery. Flexibility in choice of parallel systems is an added benefit.

Components of Dedicated Outdoor Air System

1. Total heat exchanger

Total heat exchanger is capable of handling sensible as well as latent loads. It can be an enthalpy wheel or total heat exchanger either membrane based or especially processed paper based. Sensible heat exchange is governed by temperature difference whereas latent load ‘moisture transfer’ is governed by difference in vapour pressure between exhaust and incoming air. Total energy recovery units normally have effectiveness value ranging from 0.6 to 0.8 (Mumma, 2007). Total heat exchanger is good energy saving option in hot and humid climate. It reduces the cooling capacity requirement of subsequently used cooling coil.

2. Sensible heat exchanger

Sensible heat exchanger is capable of exchanging sensible heat only. In all DOAS configurations, sensible heat exchange device is placed after the cooling coil. Sensible heat exchange devices can be avoided when air can be supplied at low temperature (below 13^{o}C) and saturated, directly into the conditioned space.

3. Cooling Coil

Cooling coils are used to cool and dehumidify air to handle the entire latent load and some portion of sensible load. Cooling coils can be operating in DX system or chilled water circulation. In DOAS primary function of cooling coil is to dehumidify the air and not to cool it.

4. Desiccant Dehumidification

Compressor based dehumidification is energy intensive because process air has to be cooled below its DPT and sometimes reheated to ensure comfortable supply of indoor air. Dehumidification through desiccates (liquid or solid) can be a potential alternative to these dehumidification systems. As a rule desiccant systems are generally better choice if dew point temperature is below 4^{o}C (Mumma, 2001). Desiccant systems are energy efficient because they allow direct expansion systems to work at higher evaporator temperature. Performance of desiccant dehumidification is measured by dehumidification effectiveness, which is the ratio of actual moisture transfer to the maximum possible moisture transfer during dehumidification. Jain and Bansal 2007 have presented performance analysis indices for desiccant dehumidification system along with experimental study by different authors and correlations for dehumidification effectiveness.

Different DOAS configurations, enthalpy wheel along with cooling coil, enthalpy wheel along with cooling coil and sensible wheel, enthalpy wheel combined with cooling coil and passive dehumidification component, liquid desiccant combined with indirect and direct evaporative cooling, Total heat exchanger with liquid desiccant dehumidification and cooling coil, were studied and analyzed in the research.

Methodology

Relevant literatures on DOAS integration were studied and the information gathered from the literatures was used for analyzing different types of configurations. Commercially available DOAS technologies were also studied. Based on the literature a compact and energy efficient configuration was identified. Psychrometric analysis for various Indian cites for different climate conditions were performed.

After study and analysis of different configurations of dedicated outdoor air systems, cooling and liquid desiccant dehumidification of outdoor fresh air by indirect evaporative cooling of exhaust air was identified as a suitable option for integration with conventional air-conditioning systems. The detailed psychrometric analysis of the DOAS for hot and dry (Ahmedabad), warm and humid (Mumbai), composite (New Delhi) and moderate (Bangalore) climates was performed. ASHRAE Psychrometric chart software was used for psychrometric analysis.

Results and Tables

After study and analysis of different configurations of dedicated outdoor air systems an indirect evaporative cooling based dedicated outdoor air system based on cooling and desiccant dehumidification of fresh outdoor air by indirect evaporative cooling of exhaust air, is identified as a suitable option for integration with conventional air-conditioning systems. A detailed analysis of applicability of this DOAS at various climate conditions is a major issue to be addressed. Detailed psychrometric analysis of the DOAS for hot and dry (Ahmedabad), warm and humid (Mumbai), composite (New Delhi) and moderate (Bangalore) climates, were performed.

Assumptions of the Analysis

a. Direct evaporative cooling of exhaust air has humidification effectiveness of 80%.

b. Mass flow rate of fresh air inlet and exhaust air outlet is equal which is taken as 150 cfm.

c. Approach between exhaust and supply air is taken as 3°C.

d. Potassium formate (KCOOH) is chosen as the desiccant for the analysis. Desiccant properties are taken at specific gravity of 1.56 which is KCOOH concentration of 74% (Cabot 2014).

e. The weather data analysis were taken from ASHRAE Fundamentals Handbook, 2009.

f.

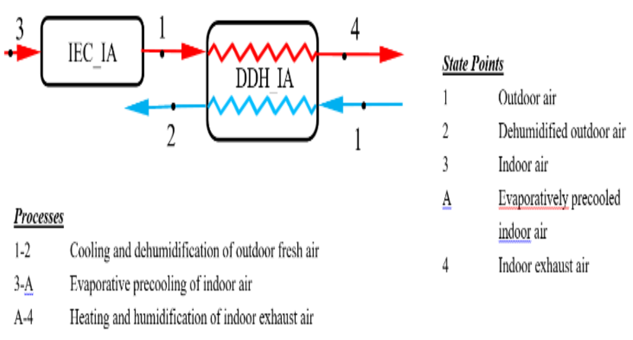

Fig -1 Schematic Drawing of Proposed DOAS

Sample Calculations

Warm and Humid Climate (Mumbai)

Outdoor Design Conditions		Indoor Design conditions	
WBT	27.4°C	DBT	27°C
MCDBT	31.0°C	ø	50%
ø	76.03%	WBT	19.5°C
w	21.81 g/kg$_{da}$	w	11.19 g/kg$_{da}$
DPT	26.3°C	DPT	15.7°C
h	86.9 kJ/kg$_{da}$	h	55.61 kJ/kg$_{da}$

Values known from design conditions and assumptions
t_1 = 31°C, t_4 = 27°C, $t_{wb.3}$ = 19°C, h_1 = 86.88 kJ/kg$_{da}$, h_4 = 81.53 kJ/kg$_{da}$, ε_h = 80%

Temperature of indoor air after humidification
$t_A = t_3 - \varepsilon_h (t_3 - t_{wb.3})$
=27 °C – 0.8 (27 °C – 19.5 °C) = 21 °C

Enthalpy of outdoor supply air after being cooled by humidification and heating of indoor air
$h_2 = h_1 - (h_4 - h_A)$
= 86.88 kJ/kg$_{da}$ – (81.53 kJ/kg$_{da}$ – 55.61 kJ/kg$_{da}$)
= 60.96 kJ/kg$_{da}$

Corresponding DBT = 25.2°C and w = 14.02 g/kg$_{da}$
Total cooling provided by humidification and heating
$Q_{12} = m_{oa} (h_1 - h_2)$
= 0.082 kg/s (86.88 kJ/kg$_{da}$ – 60.96 kJ/kg$_{da}$)
= 2.12 kW

Dehumidification effectiveness
$\varepsilon_{dh} = (w_1 - w_2) / (w_1 - w_e)$
= (21.81 g/kg$_{da}$ – 14.02 g/kg$_{da}$) / (21.81 g/kg$_{da}$ – 8.7 g/kg$_{da}$)
= 59.42 %

Quantity of water evaporated

Indirect evaporative cooling
$m_{we.iec} = m_{ia} (w_A - w_3)$
= 0.0824 kg/s (13.62 g/kg$_{da}$ – 11.19 g/kg$_{da}$) = 0.2 g/s
= 0.72 kg/h

Desiccant Humidification and heating
$m_{we.ddh} = m_{ia} (w_4 - w_A)$
= 0.0824 kg/s (20.94 g/kg$_{da}$ – 13.62 g/kg$_{da}$) = 0.6 g/s
= 2.17 kg/h

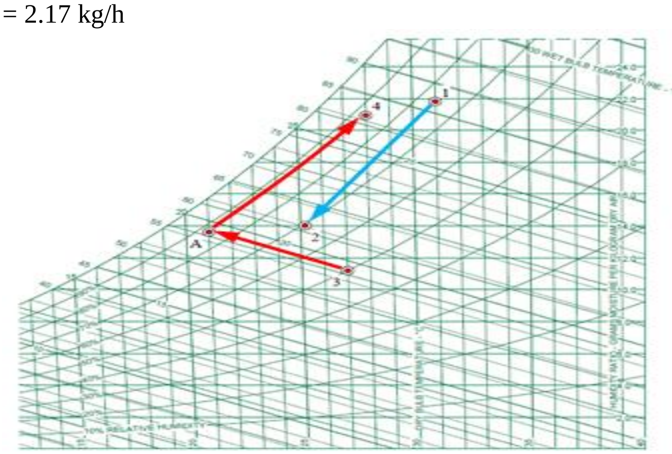

Fig -2 Psychrometric Representation of the process for Mumbai

Similar calculations were performed for Composite (New Delhi), Moderate (Bangalore) and Hot and Dry (Ahmedabad) climate conditions. The psychrometric charts are given in Fig-3, Fig -4 and Fig -5 respectively and temperatures, relative humidities for each state points along with cooling effects are given in Table -1 and Table -2.

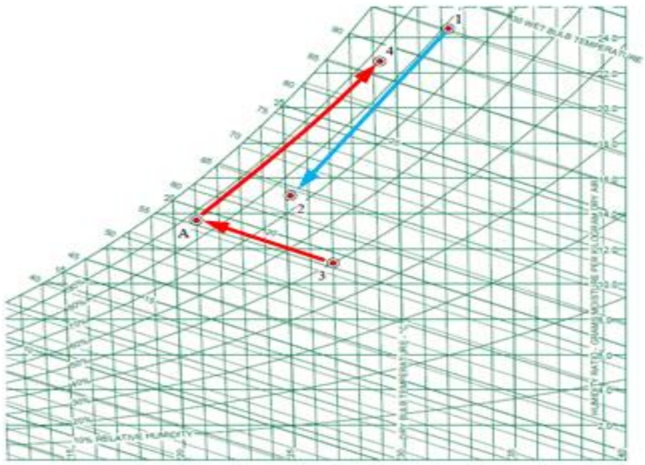

Fig -3 Psychrometric Representation of the process for New Delhi

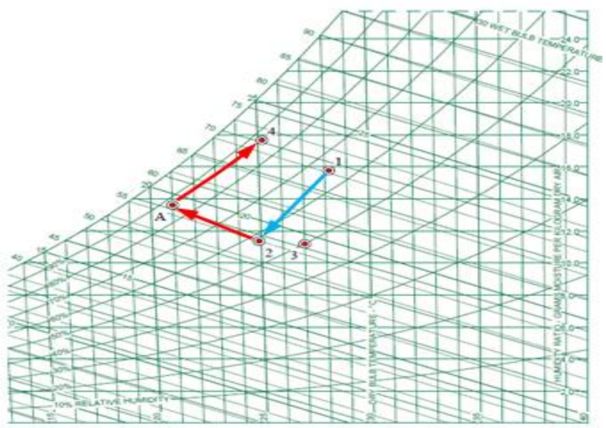

Fig -4 Psychrometric Representation of the process for Bangalore

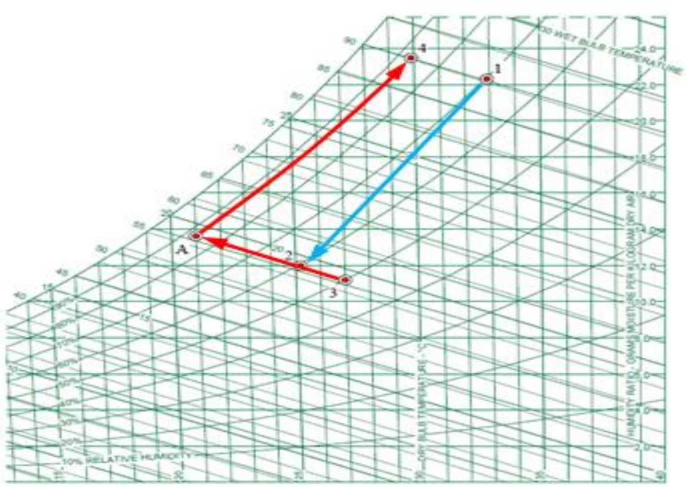

Fig -5 Psychrometric Representation of the process for Ahmedabad

Table -1 Temperature, relative humidity and cooling effect obtained from psychrometric chart for Mumbai and New Delhi

	Mumbai			New Delhi		
State Points	DBT °C	rh, %	Cooling Effect, kW	DBT °C	rh, %	Cooling Effect, kW
1	31.0	76.0	2.12	32.3	79.0	2.60
2	25.2	69.3		25.2	74.2	
3	27.0	50.0		27.0	50.0	
A	21.0	86.9		21.0	86.9	
4	28.0	86.9		29.2	86.9	

Table -2 Temperature, relative humidity and cooling effect obtained from psychrometric chart for Bangalore and Ahmedabad

	Bangalore			Ahmedabad		
State Points	DBT °C	rh	Cooling Effect, kW	DBT° C	rh, %	Cooling Effect, kW
1	28.2	65.2	1.2	32.9	69.8	2.83
2	24.9	57.5		25.2	59.5	
3	27.0	50.0		27.0	50.0	
A	21.0	86.9		21.0	86.9	
4	25.2	86.9		29.9	86.9	

Conclusions

An indirect evaporative cooling based DOAS was examined for its suitability for application in Indian cities with different climate conditions. Psychrometric analysis was performed for various climate conditions of different Indian Cities DOAS configuration was suitable for warm and humid climate which have fairly high relative humidity values throughout the year.

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References

i. *American Society of Heating, Refrigerating and Air-Conditioning Engineers Handbook Fundamentals, 2009, SI Edition.*

ii. *Cabot formate brines potassium formate, 2103, retrieved from http://www.formatebrines.com/Portals/2/Datasheets/Cabot_Data_Sheet-POTASSIUM-FORMATE-METRIC-UNITS.pdf, last accessed 18 October 2014*

iii. *Jain S and Bansal P K, 2007, Performance Analysis of Liquid Desiccant Dehumidification Systems, International Journal of Refrigeration, vol 30, pp 861-872.*

iv. *Mumma S A, 2001, Dedicated OA System, IAQ Applications.*

v. *Mumma S A, 2001, Shank K M, Achieving Dry Outside Air in an Energy Efficient Manner, ASHRAE Transactions, vol 107, pt 1.*

vi. *Mumma S A, 2007, DOAS and Desiccants, Engineered Systems.*