HPL_IITB

2016 Purdue Conferences
Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

DESIGN INTEGRATION OF DEDICATED OUTDOOR AIR SYSTEM WITH VARIABLE REFRIGERANT FLOW SYSTEM

Paper # 22439

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214 A&B, Stewart Center, Purdue University

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OUTLINE OF PRESENTATION

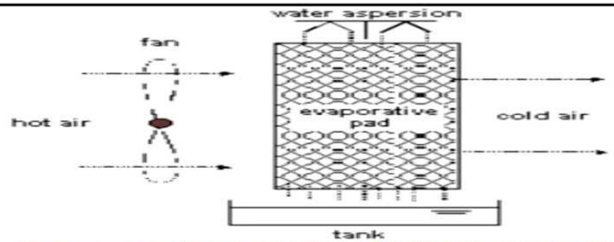
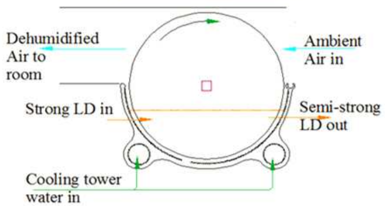
- ***Background and Need***
  - » Variable Refrigerant Flow, VRF, systems
  - » Dedicated Outdoor Air systems, DOAS
  - » Identified as best option
- ***DOAS Configurations***
  - » Study, comparison and identification of DOAS configurations for each Indian climate zone
- ***Psychrometric and Theoretical Analysis***
  - » Selected of preferred DOAS configuration
- ***Conclusions and Recommendations***

BACKGROUND AND NEED

- ***Integrating VRF systems with DOAS***
  - » Application of inverter driven variable speed compressors in VRF outdoor units offer good part load efficiency compared to VRV system
  - » Introduction of fresh Outdoor Air in conditioned space will limit load and energy required

- ***Objective***
  - » Identify optimal DOAS configurations to integrate with VRF systems

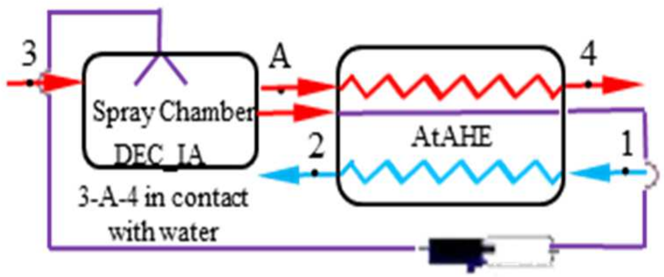
LITERATURE REVIEW

Sr #	Paper	Schematic	Feature
1.	Wu et al. (2009)		Theoretically investigated heat and mass transfer in DEC areas
2	Heidarinejad et al (2008)		$\varepsilon_{\text{cross flow heat exchanger}} \sim$ 55 to 61%
3	Fernández-Seara et al. (2011)		$\varepsilon_{\text{exhaust heat recovery systems}} \sim$ around 60%
4	Rane and Chavan (2014)	 Rotating Contacting Device, RCD Indian patent # 205362  9 enhanced passage Al extrusion Indian patent # 1349/MUM/2013	RCD + Plastic Heat Exchanger, PHE for 45 cfm ε_{PHE} = 82.6%, ε_{WBT} = 101.5% U_o = 18.0 W/m^{2}K dp_{ea} = 39.2 Pa dp_{oa} = 17.6 Pa

TEMPERATE CLIMATE

t_{dbt} = 25 to 30°C, rh < 75%, Summer, Cities: Bangalore, Pune

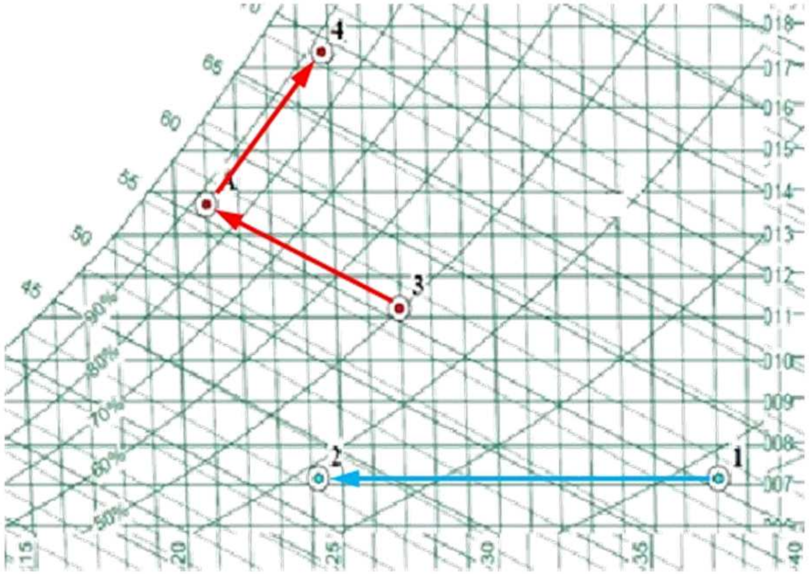
» IEC of OA using Evaporative Cooling + Diabatic Heating and Humidification of EA



State points

1 OA
2 OA after sensible cooling
3 IA
A IA after Evaporative Cooling
4 IA after diabatic heating and humidification

Water gets sprinkled in Spray chamber to evaporatively cool IA and flows concurrently with IA to further humidify it



Process for Pune during Summer

Q_{oa} = 1.2 kW, mf_{wc} = 0.7 g/s

TEMPERATE CLIMATE

t_{dbt} = 25 to 30°C, rh < 75%, Monsoon, Cities: Bangalore, Pune

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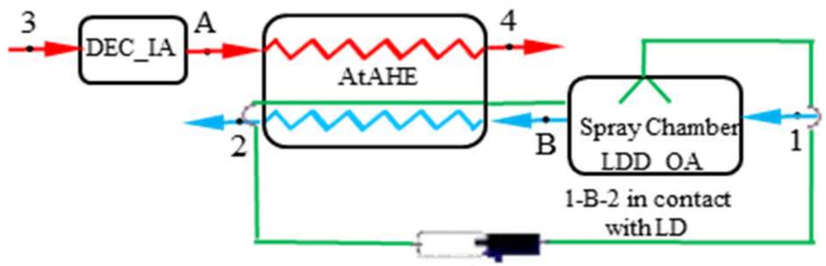
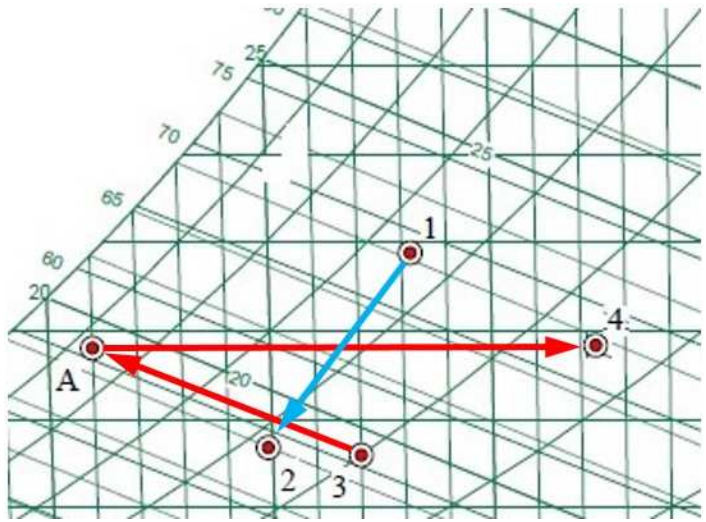
» LDD and IEC of OA using Evaporative Cooling + Sensible Cooling of EA



State points
1 OA
B OA after Liquid Desiccant Dehumidification
2 OA after sensible cooling
3 IA
A IA after Evaporative Cooling
4 IA after Sensible heating

Liquid Desiccant gets sprinkled in spray chamber to dehumidify and cool OA and flows concurrently with OA to further dehumidify it



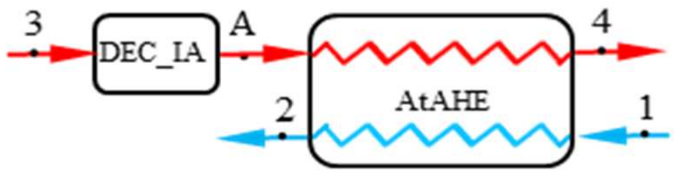
Process for Bangalore during Monsoon

Q_{oa} = 1.12 kW, mf_{wc} = 0.2 g/s

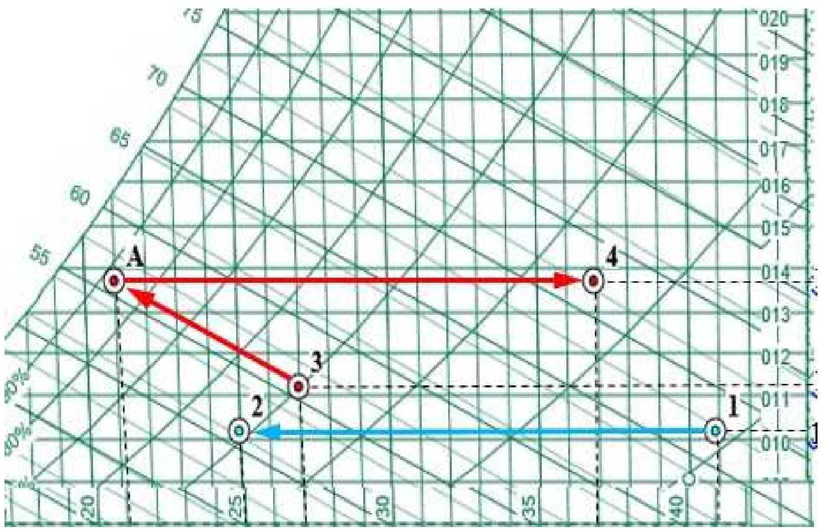
HOT AND DRY CLIMATE

$t_{dbt} > 30^oC$, rh < 55%, Summer, Cities: Ahmedabad, Jaipur

» IEC of OA using Evaporative Cooling + Sensible Heating of EA



State points
1 OA
2 OA after sensible cooling
3 IA
A IA after Evaporative Cooling
4 IA after sensible heating



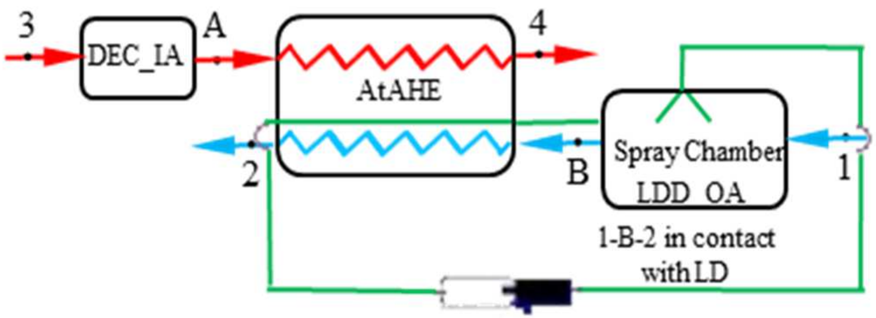
Process for Ahmedabad during Summer

Q_{oa} = 1.39 kW, mf_{wc} = 0.3 g/s

HOT AND DRY CLIMATE

t_{dbt} > 30°C, rh < 55%, Monsoon, Cities: Ahmedabad, Jaipur

» LDD and IEC of OA using Evaporative Cooling + Sensible Cooling of EA



State points
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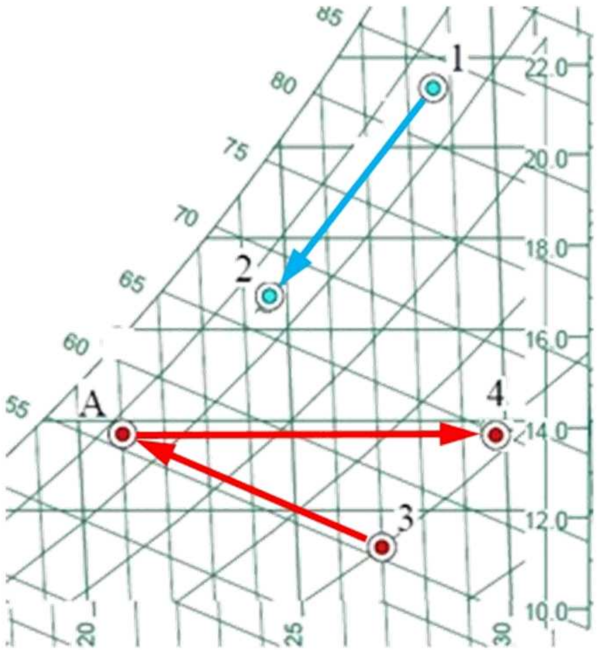


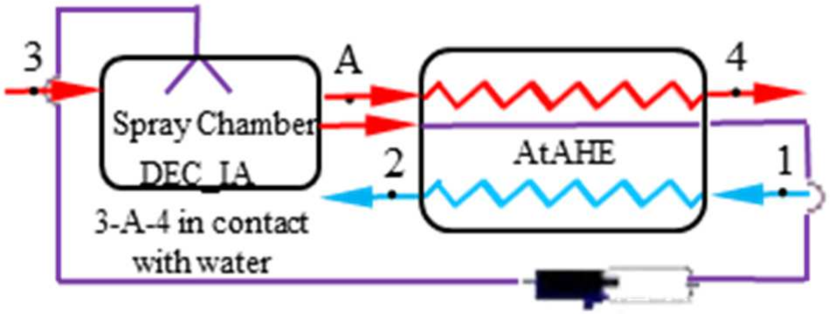
Process for Jaipur during Monsoon

Q_{oa} = 1.12 kW, mf_{wc} = 0.22 g/s

WARM AND HUMID CLIMATE

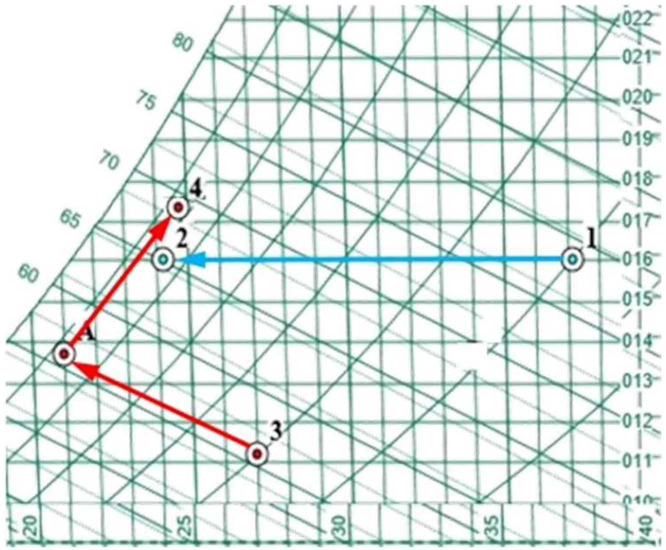
t_{dbt} > 25°C, rh > 55%, Summer, Cities: Mumbai, Kolkata, Chennai

» IEC of OA using Evaporative Cooling + Diabatic Heating and Humidification of EA



State points
1 OA
2 OA after sensible cooling
3 IA
A IA after Evaporative Cooling
4 IA after diabatic heating and humidification

Water gets sprinkled in Spray chamber to evaporatively cool IA and flows concurrently with IA to further humidify it



Process for Chennai during Summer

Q_{oa} = 1.39 kW, mf_{wc} = 0.5 g/s

WARM AND HUMID CLIMATE

$t_{dbt} > 25^oC$, rh > 55%, Monsoon, Cities: Mumbai, Kolkata, Chennai

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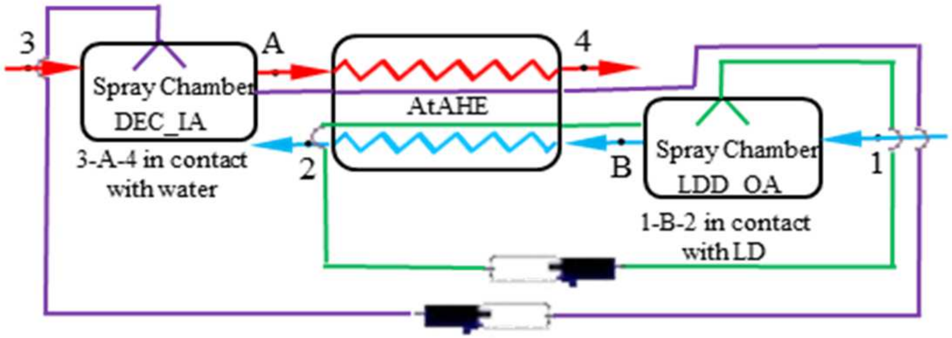
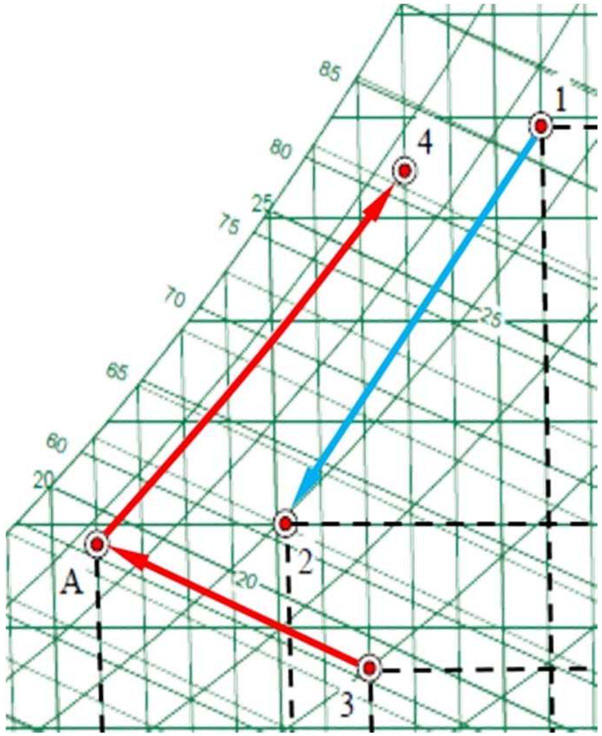
» LDD and IEC of OA using Evaporative Cooling + Sensible Cooling of EA



State points
1 OA
B OA after Liquid Desiccant Dehumidification
2 OA after sensible cooling
3 IA
A IA after Evaporative Cooling
4 IA after diabatic heating and humidification

Water is sprinkled in left chamber flows concurrently with IA to further humidify it. Liquid Desiccant sprayed in right chamber flows concurrently with OA to further dehumidify and cool it



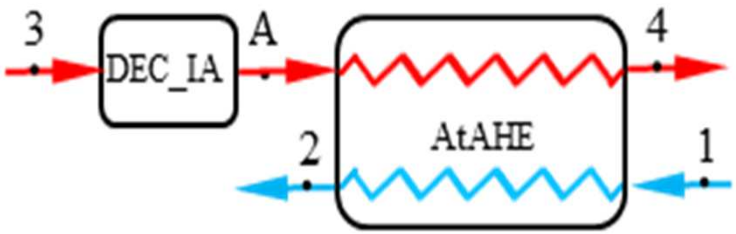
Process for Mumbai during Monsoon

Q_{oa} = 2.1 kW, mf_{wc} = 0.7 g/s

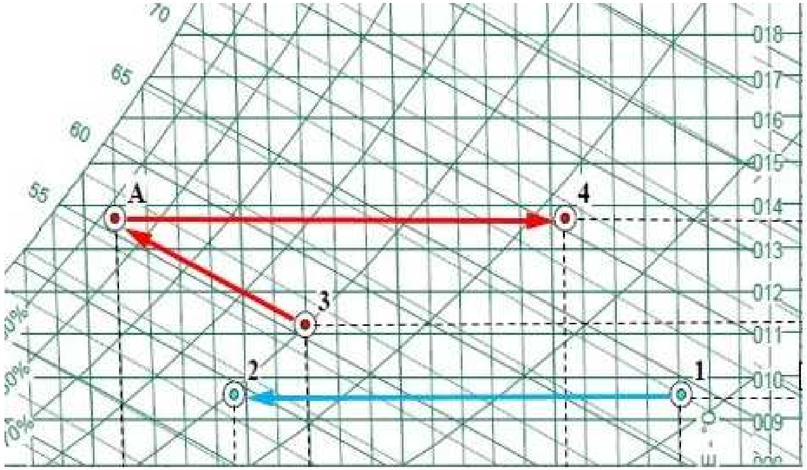
COMPOSITE CLIMATE

6 months or more don't fall under any category, Summer, Cities: Delhi, Hyderabad

» IEC of OA using Evaporative Cooling + Sensible Heating of EA



State points
1 OA
2 OA after sensible cooling
3 IA
A IA after Evaporative Cooling
4 IA after sensible heating



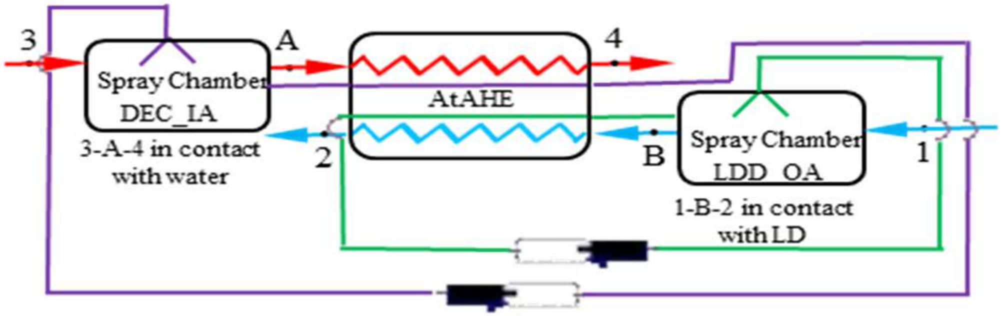
Process for Hyderabad during Summer

Q_{oa} = 1.39 kW, mf_{wc} = 0.22 g/s

COMPOSITE CLIMATE

6 months or more don't fall under any category, Monsoon, Cities: Delhi, Hyderabad

» LDD and IEC of OA using Evaporative Cooling + Sensible Cooling of EA



State points
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2 OA after sensible cooling
3 IA
A IA after Evaporative Cooling
4 IA after diabatic heating and humidification

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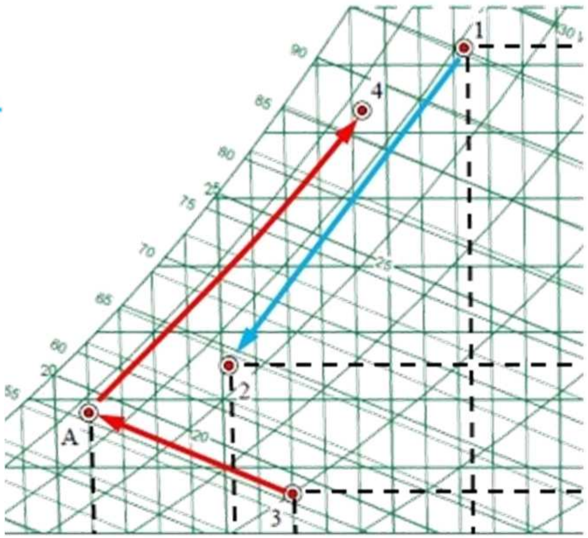


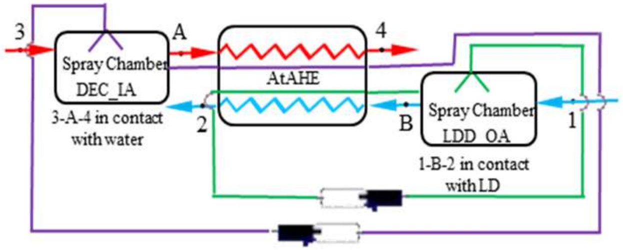
Process for Delhi during Monsoon

Q_{oa} = 1.7 kW, mf_{wc} = 0.5 g/s

THEORETICAL ANALYSIS

Liquid Desiccant Dehumidification and Indirect Evaporative Cooling of OA

Assumptions: $\varepsilon_{humidifier}$, ε_{he} 80%, $t_{1.db}$ 31.0°C, $t_{3.db}$ 27.4°C, $volf_{ia}$ 0.07 m³/s 150 cfm, $volf_{oa}$ 0.07 m³/s 150 cfm, $approach_{oa}$ 3°C



State points
1 OA
B Dehumidified OA
2 OA after desiccant dehumidification
3 IA
A Indoor Air after Evaporative Precooling
4 Indoor Air after heating and humidification

Process 1 to 2 Desiccant dehumidification and cooling of outdoor air
Process 3 to A Indirect evaporative cooling of exhaust air
Process A to 4 Direct humidification and heating of exhaust air

Temperature Calculations

t_A $= t_3 - \varepsilon_h (t_{3.db} - t_{3.wb})$ **= 21.0°C** = 27oC – 0.8 (27 – 19.5)°C

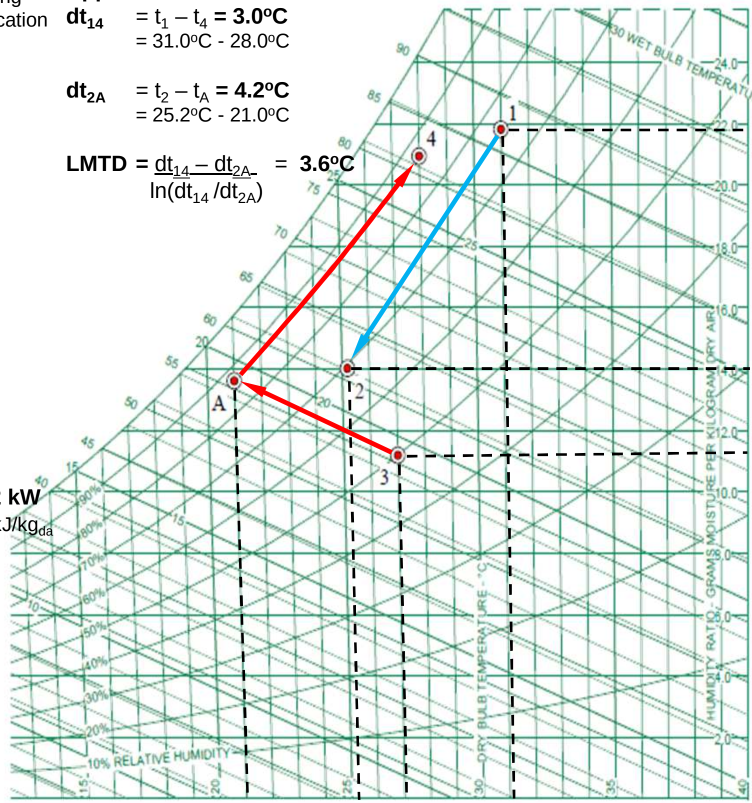
t_4 $= t_1 - approach_{oa}$ **= 28.0°C** = 31°C - 3°C

Approach

dt_{14} $= t_1 - t_4$ **= 3.0°C**
= 31.0°C - 28.0°C

dt_{2A} $= t_2 - t_A$ **= 4.2°C**
= 25.2°C - 21.0°C

LMTD $= \dfrac{dt_{14} - dt_{2A}}{\ln(dt_{14}/dt_{2A})}$ **= 3.6°C**



Specific Parameters	Units	oa 1	oa 2	ia 3	ia A	ia 4	Water Consumed IEC	DHH	Total	Units
t_{db}	°C	**31.0**	**25.2**	**27.0**	21.0	**28.0**	0.20	0.6	0.8	g/s
t_{wb}	°C	**27.4**	21.0	19.5	19.5	26.2	0.01	0.04	0.05	kg/min
t_{dp}	°C	26.3	19.2	15.7	18.7	25.6	0.71	2.2	2.9	kg/h
ϕ, rh	%	76.0	69.3	**50.0**	86.9	86.9				
W	g/kg_{da}	**21.8**	**14.0**	**11.2**	13.6	20.9				
h	kJ/kg	86.9	61.0	55.6	55.6	81.5				
mf	g/s	82.0			82.0					
	kg/min	4.9			4.9					
	kg/h	295			295					
volf	m³/s	0.07			0.07					
	cfm	150			150					

Heat Interactions

$Q_{oa} = Q_{12}$ $= mf_{oa} (h_1 - h_2)$ **= 2.12 kW**
= 0.082 kg/s (86.9 – 60.9) kJ/kg_{da}

$Q_{ia} = Q_{3A4} = Q_{A4}$ $= mf_{oa} (h_4 - h_3)$ **= 2.12 kW**
= 0.082 kg/s (81.5 kJ/kg_{da} – 55.6 kJ/kg_{da}

Water Consumption

mf_{wc} $= mf_{ia} (W_4 - W_3)$ **= 0.8 g/s**
= 0.082 kg/s (20.9 - 11.2) g/kg_{da} = 0.048 kg/min = 2.86 kg/h

$mf_{we.dhh}$ $= mf_{ia} (W_4 - W_A)$ **= 0.6 g/s**
= 0.082 kg/s (20.9 - 13.6) g/kg_{da} = 0.036 kg/min = 2.16 kg/h

$mf_{we.iec}$ $= mf_{ia} (W_A - W_3)$ **= 0.2 g/s**
= 0.082 kg/s (13.6 - 11.2) g/kg_{da} = 0.012 kg/min = 0.71 kg/h

CONCLUSION

- ***DOAS + VRF energy efficient to meet ASHRAE stds***
- ***DOAS Configurations for each Indian Climate Zone were identified***
- ***LDD + IEC of OA is identified as best DOAS option for hot and humid conditions***
  - » Versatile DOAS: LDD + IEC option for Monsoon, only IEC can be used for summer
  - » Can handle high outdoor sensible and latent heat load
  - » Can be used for mismatched flow rates of OA and IA
  - » Can handle any kind of internal hea load, reheating not required

RECOMMENDATIONS

- ***Design of regeneration and cooling system for Liquid Desiccant***
  - » Regeneration of liquid desiccant through condenser heat recovery
  - » Using solution heat exchangers for cooling strong liquid desiccant solution by exchanging heat with incoming weak desiccant solution

THANKS