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Cold Air Distribution System

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Cold air distribution systems supply air at 40 – 45°F instead of the conventional 55°F to cut down air flow rate, air handling unit size and duct dimensions. Similarly using high-rise chilled water coils, water flow rate, pump capacity and pipe sizes can be cut down. Thus saving operating costs. Why not use more such systems in new HVAC designs for commercial and office buildings?

In a conventional air conditioning system (CAC), the supply air temperature is about 55°F(13°C) for comfort air conditioning. This gives a temperature differential of 20°F (11°C) between room 75°F (24°C) and supply air. In a cold air system (CAS), the supply air temperature will be at about 45°F (7°C) for a room temperature of 78°F(25.6°C) which, as will be seen later, is acceptable in CAS– yielding a temperature differential of 33 – 38°F (0.5 – 3°C). Accordingly, in a CAS, the dehumidified air flow rate will be only about 50-60% of the value in CAC for the numbers cited above. Although there is a great deal more to CAS, this is its trademark.

Description

Figure 1 shows the summer schematic for the CAS. The inside design conditions are 78°F db and 35% rh. The return air is divided into two streams — the first is the quantum of air that is equal to the outside air-flow rate and which is exhausted through a heat wheel. The second — the remainder of the return air is drawn back directly by the AHU.

The incoming outside air is cooled and dehumidified by the first stream of the return air, which as noted earlier, is exhausted through the heat wheel. The AHU therefore handles a mixture of outside air, that emerges from the heat wheel — duly cooled and dehumidified — and the second stream of return air that arrives directly from the room. It is this mixture that passes through the cooling coil of the AHU. **Figure 2** shows the cooling process on a psychrometric chart.

Brine is supplied to the cooling coil at 35°F (in lieu of 44 to 45°F used in a CAC). Thus, the air that leaves the coil, can be at 40 – 45°F.

Low Room RH Enables Use of High DB

The selected room relative humidity is 35%. This low rh — even at 78°F db, as can be seen from the ASHRAE Comfort Chart (**Figure 3**) is close to the comfort level obtained at 74°F db and 55% rh. In other words full advantage is taken of the lower relative humidity that is readily achieved in the CAS, to elevate the room db to 78°F. This, in turn, increases the temperature differential between supply air and room correspondingly — that is to say, by about 4°F. The resulting benefit will be a further reduction in the dehumidified air flow rate.

CAS Compared to CAC

It is best however to study the CAS in relation to the conventional systems, using a worked example.

Consider the air conditioning requirements of an office area of 22,500 ft^2. Other relevant design data is shown below:

1. The inside design conditions will be
   a. 74°F db and 55% rh for CAC
   b. 78°F db and 35 – 40% rh for CAS
2. All other particulars are identical for both CAC and CAS and are listed below:
   1. Area 22500 ft^2
   2. Outside design conditions :
   Summer : db – 95 deg F
   wb – 83 deg F

Monsoon : db – 85 deg F

wb – 82 deg F

3. Occupancy : 450 persons
4. Outside : Air 15cfm per person
5. Lights : 2 W/sft.
6. Appliances : 10kW

Calculations

Based on this data, three cases have been worked out and analyzed in this article:

1. CAC – 1 : Conventional air conditioning.
2. CAC – 2 : Conventional air conditioning with heat wheel.
3. CAS : Cold air system.

For CAC – 1, the air conditioning load estimates, including transmission and solar, have been made using standard procedures – essentially, the ADP method exemplified in the Carrier System Design Manual.

For CAC – 2 and CAS, the modified procedure is outlined below :

1. Enter with supply air temperature of 45°F.
2. Calculate SA flow rate as
   $$\frac{RSH}{1.08^{V} \times (78 - 45)}$$
3. Calculate exhaust air and return airflow rates.
4. Find heat wheel leaving conditions.
5. Use mixture equations to arrive at entering conditions for the AHU brine cooling coil.
6. Find ADP using the known parameters i.e. room db, supply air db and coil bypass factor.
7. Find $W_{s\text{-}ADP}$ (gr/lb)
8. Calculate W_s of air leaving the coil (gr/lb)
9. Calculate latent heat load due to OA using the following formula:
   OA cfm × 0.68 × 0.05 ×
   {Enthalpy of air leaving heat wheel – Room Enthalpy}
10. Add latent heat gain due to people to step 9 and arrive at RLH.

11. Calculate “Ws-sa reqd” to meet the RLH calculated in Step 10.
12. Calculate “ΔWs-sa reqd” from Step 10.
13. Check with “Ws-sa avail” (as calculated in Step 8).
14. If the discrepancy between “Ws-sa reqd” and “Wssa avail” is not acceptable, enter the calculation with a value of supply air, other than 45°F and repeat procedure.

Calculations have been made for the intermediate season also in addition to Summer and Monsoon Seasons. The following months constitute the 3 seasons :

Summer : March, April & May

Monsoon : June, July, August, September and October

Intermediate Season : November, December, January and February

The inside design conditions used for the intermediate season i.e., 91°F-db and 70°F-wb have been arrived at on the basis of IMD Data (Climatological Tables of Observatories in India, 1951 - 1980 Fifth Edition 1999).

Results

The highlights of the results of the study are shown in **Tables 1, 2, 3 and 4**.

Table - 1 : Study of TR & CFM Requirements of CAC-1, CAC2 & CAS

Sl. No.	Description	CAC -1			CAC-2			CAS		
		Sum.	Mon.	Int.	Sum.	Mon.	Int.*	Sum.	Mon.	Int.
1	TR	118	88	82	89	63	84	77	55	66
2	ADP	55	54	55.5	55	54	54			
3	Indicated Summer – cfm	42359			42360					
4	Adjusted Summer – cfm	42359			42360			19875		
5	Monsoon – cfm		22694			22700			12000	
6	Supply Air Temperature	56	64	56.5	56	64	55	45	45	

Table 2 : Power Requirements

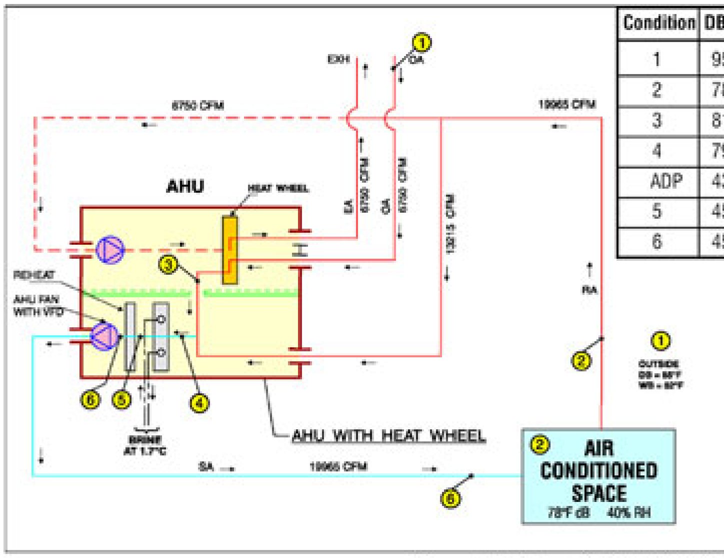
Sl. No.	Description	CAC		CAS	Remarks	
		RTAB - 108 W/o HW	CGA 600 W/HW	CGA 600 W/HW	CAC - 1	CAC - 2
1	Chiller – kW	165	113	108	Higher by 50%	Higher by 30%

2	Chilled water / Brine Pumps – kW	11	7.4	4.4	Higher by 250%	Higher by 250%
3	AHU Fan – kW	22	22	15	Higher by 50%	Higher by 50%
4	Heat Wheel Exhaust Fan – kW	–	3	2.2	_	_
5	Reheat – kW	See Note *	25	25	See Note *	See Note *
		198	**170.4**	**154.6**	**highby 40%**	**highby 20%**

Note : * Reheat for CAC has not been shown since it is not usually provided

Table - 3 : Chiller Selection

Sl. No.	Description		CAC		CAS
			RTAB – 108 W/o HRC	**CGA – 600 W/HRC**	**CGA – 600 W/HRC**
1	Total Capacity required	– TR – kW	118 420	89 315	78 275.6
2	No. of Chillers		2	2	2
3	Capacity required per Chiller	– TR – kW	59 210	44.5 157.0	39 137.8
4	Capacity of Selected Chiller	– TR – kW	60 212	43.5 154	37.4 132.2
5	Flow rate	– l/s – gpm	10.1 161.6	7.35 117.6	3.65 58.4
6	Compressor – Type		Screw	Scroll	Scroll
7	Power input at Design Conditions	– kW	82.5	56.5	54
8	KW / TR		1.4	1.3	1.4
9	Total Power	– kW	165	113	108
10	Operating weight of each machines	– kgs	2410	1270	1270
11	Refrigerant Charge	– kgs	56	28	28
12	L x W x H – mtrs		3.1 x 2.1 x 2.1	2.3 x 1.9 x 1.6	2.3 x 1.9 x 1.6



Condition	DB(°F)	WB(°F)	RH(%)	DP(°F)	Ws(gr/lb)	h(btu/lb)
1	95.00	83.00	60.89	79.36	152.617	46.85
2	78	60.3	35	48.17	49.849	26.52
3	81.4	65.85	43.96	57.39	70.40	30.57
4	79.15	62.25	38.34	51.39	70.40	30.57
ADP	43.2	43.2	100	43.2	41.2	16.74
5	45	44.55	96.66	44.11	42.74	17.40
6	45	44.55	96.66	44.11	42.74	17.40

Figure 1 : Schematic for CAS (Summer)

Click to view the clear picture

CAS Features

The following features of the CAS may be noted straight away:

1. Plant capacity (in the case of CAS & CAC – 2) is determined by the enthalpy difference between entering air and leaving air for the cooling coil (and not directly by the heat gain calculations made using standard procedures.)
2. The required plant capacity is smaller in CAS (both with respect to CAC – 1 and CAC – 2). This is due to the use of heat wheel. (It may be noted incidentally that the use of heat wheel has also brought down the load of CAC – 2 as compared to CAC – 1).
3. The heat wheel is an integral part of the system. It plays a major role in the reduction of plant capacity. The lowest enthalpy that the OA can be cooled down to by a heat wheel in an air conditioning system is the room enthalpy. Accordingly, it is more effective, when room enthalpy is lower. In CAS, the room enthalpy is 26.52 btu/lb as compared to 26.8 in the case of CAC.
4. The air flow rate is reduced substantially i.e., about 50% (from 42,360 cfm to 19,875 cfm).
5. Reheat requirement has been recognized. This can be provided by adding a heat recovery condenser in the chiller package thus avoiding use of any external source of energy.
6. As noted already, the CAS uses a smaller air flow rate at a lower supply air temperature. This calls for special supply air diffusers, which, are designed specially

to produce the necessary greater induction (or entrainment) as compared to standard diffusers used in a CAC. Also, they are designed to avoid possibility of condensation on the surface of the body of the diffuser, the temperature of which will be lower than in a CAC.

One manufacturer offers the following features :

- addition of insulation on top of housing.
- modified wax (temperature sensor) in the cooling thermostat.

A second manufacturer has introduced Direct Jet Induction Diffusers. In these diffusers, triangular shaped air jets are employed. They produce an ideal peripheral surface to cross-sectional area ratio to maximize induction effect. Supply air is introduced into the diffuser's core, accelerated, shaped, and at an angle that provides a low velocity, low pressure region at the diffuser's outlet. This design accomplishes higher induction ratios than round air jets. The induced room air impinges on the surfaces of the diffuser at a relatively high velocity and maintains a surface temperature approximately 12°F above the diffuser's supply air temperature. This feature eliminates condensation problems with supply air temperatures as low as 35°F.

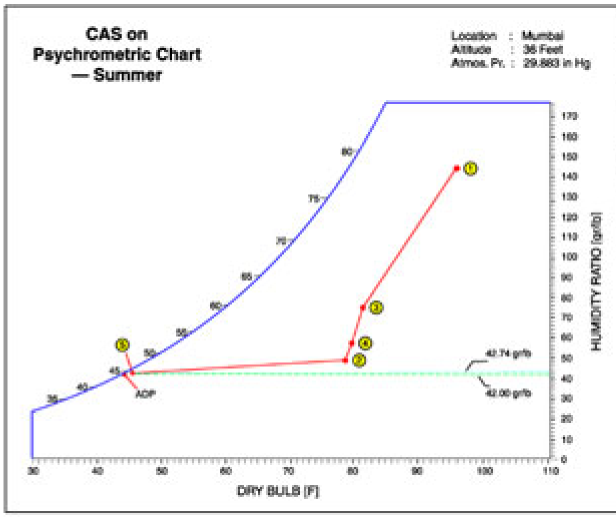
In these special diffusers, the velocities kept at a high value (1500 fpm, both at design value and turn-down air flows) create a high induction and rapid entrainment of room air into the supply air. This mixing quickly raises the temperature. In a 74°F room, 40°F supply air is warmed to 70°F within 2.5 horizontal feet of the diffuser, with less than two inches of drop at both full and part flows. Within four horizontal feet of the diffuser, and less than three inches drop, the air is warmed to room temperature. All these diffusers have been tested for their characteristics in state-of-the art laboratories and need to be imported. They are manufactured by such well known names as Acutherm (Thermafusers), Titus, etc.,

7. The low room rh which, characterizes CAS, also helps improve the overall indoor air quality. A crisp-cool sensation is experienced by the occupants.

   Concentration of toxic substances will also be lower and chances of formation of mildew are reduced / eliminated.

   High humidity problems have generally been well identified in Monsoon Asia. We are no less familiar in our own country – which is also a part of Monsoon Asia. The CAS is particularly adapted to tackle this problem.

8. Chilled water flow rates are substantially lower (1.5 gpm / ton as coils are selected for 20 to 23°F rise as compared to the conventional value of 8 to 10°F. This reduces pumping, piping and pipe insulation requirements.



Condition	DB(°F)	WB(°F)	RH(%)	DP(°F)	Ws(gr/lb)	h(btu/lb)
1	95.00	83.00	60.89	79.36	152.617	46.85
2	78	60.3	35	48.17	49.849	26.52
3	81.4	65.85	43.96	57.39	70.40	30.57
4	79.15	62.25	38.34	51.39	70.40	30.57
ADP	43.2	43.2	100	43.2	41.2	16.74
5	45	44.55	96.66	44.11	42.74	17.40
6	45	44.55	96.66	44.11	42.74	17.40

LEGEND			
DB	Dry Bulb Temp.	DP	Dew Point Temp.
WB	Wet Bulb Temp.	Ws	Grains Per Pound
RH	Relative Humidity	h	Enthalpy

Figure 2 : CAS on Psychrometric Chart (Summer)

Click to view the clear picture

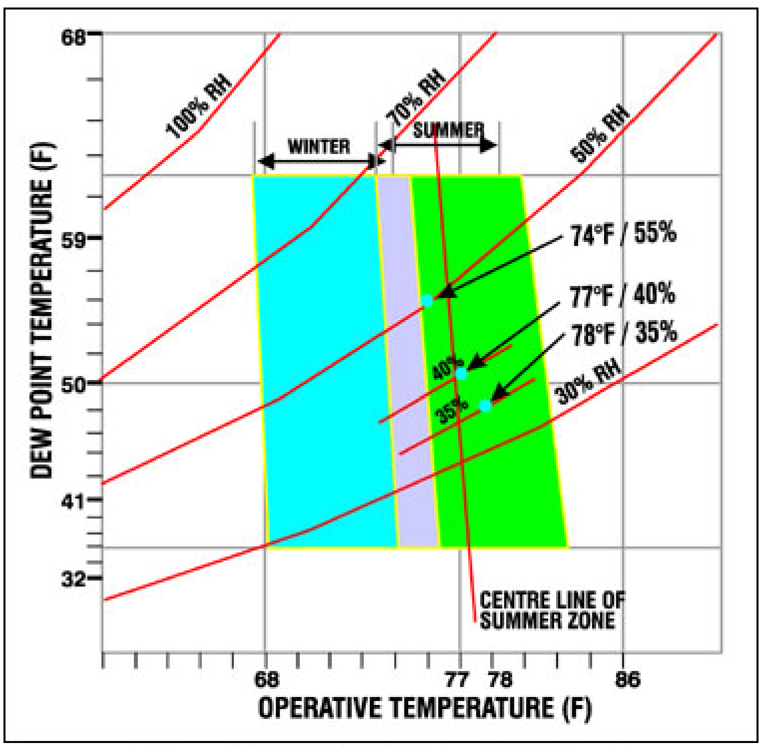


Figure 3 : ASHRAE Comfort Chart

Table - 4 : Comparative Study of Costing for CAC - 1, CAC - 2 & CAS

Sl. No.	Description	CAC – 1 Amount - Rs.	CAC – 2 Amount - Rs.	CAS Amount - Rs.
1	Trane Air Cooled Brine Chilling			2875000

	Machine			
1	Trane Air Cooled Water Chilling Machine	4110000	2875000	
2	Chilled Brine Pumpsets			66000
2	Chilled water Pumpsets	140000	100000	
3	Double skin Composite Air Handling Unit	800000	900000	700000
4	Heat Wheel		600000	600000
5	Sheet metal work	860000	860000	828100
6	Thermal insulation	400000	400000	200000
7	Acoustic Insulation	45500	45500	28000
8	Chilled Brine Piping			136600
9	First Charge of Ethylene Glycol			30000
10	Chilled Water Piping	215300	211000	
11	Hot Water Piping			144100
12	Controls	328500	299600	280400
13	Electrical Work	328500	299600	280400
	TOTAL	**7227800**	**6590700**	**6168600**

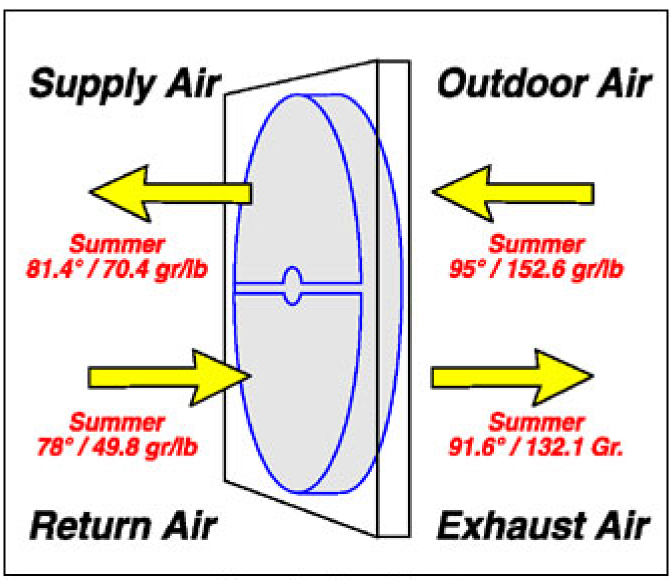


Figure 4 : Heat Wheel

CAS Benefits & Advantages

CAS Benefits & Advantages The benefits and advantages of CAS can now be listed :

1. Plant capacity reduced from 118 ton to 77 ton (reduction 35%) with respect to CAC – 1 and 88 ton to 77 ton (reduction 12%) with respect to CAC – 2.

2. Air flow rate reduced from 42,360 cfm to 19,875 cfm (reduction of 50%)
3. Connected power reduced from 198 kW to 155 kW without reheat and 170 kW to 155 kW with reheat. (reduction of 25% and 13% respectively).
4. Overall indoor air quality superior.
5. Chances of mold and mildew formation are eliminated.
6. Lower AHU noise levels.
7. Ducting will occupy less space in the false ceiling.
   As a result,
   • Larger floor-to-false ceiling heights (6" to 9") can be achieved; this will offer greater freedom and flexibility in false ceiling design.
   • More space will be available in the void above the false ceiling for other services.
   • In some cases, it may be possible to gain an extra floor(s) in a multistorey building, because of reduction in height of the ducting that the smaller duct sizes will permit.
8. Plant capacity required and performance less sensitive to ventilation requirements. For example, when ventilation rate is increased from 15 cfm / person to 20 cfm / person, the increase in plant capacity in the case of CAS is about 5% as compared to 12% in CAC. Likewise, there is no increase in reheat requirement of 26kW worked out for ventilation rate of 15 cfm/ person.
9. Lower first cost in electrical work, DG set capacities, transformer capacities, maximum demand charge, deposit with Electricity Boards, etc.
10. Lower ducting cost.
11. Lower piping cost.
12. Lower pumping cost.
13. Lower energy costs.
14. Costing : The estimated cost for the three cases considered is shown below :

	First Cost (in Rs. Lakhs)		**Energy Cost (in Rs. Lakhs)**	
	Alt – 1	**Alt – 2**	**Alt – 1**	**Alt – 2**
CAC	73	66	18	15
CAS	62	–	12.5	–

The above costs include chillers, pumpsets, AHUs, sheet metal work, diffusers, fire dampers, volume control dampers, thermal insulation (50 mm EPS or equivalent for all ducting), acoustic lining, chilled water / brine piping, controls and electrical work; also, import duty has been calculated at 55% for chillers and special diffusers (for CAS only).

Heat wheel, VFD for AHU fan motors, hot water pumpsets, hot water coil and hot water piping have also been included for CAS.

The estimate for CAC – 2 also includes a heat wheel.

Quantities for sheet metal work with diffusers and other accessories, thermal insulation, acoustic lining etc., have been taken from schematic layouts that were prepared for this study.

A comparative study of costing has been furnished in **Table – 4**. It will be seen that while CAS is about 17% less expensive than CAC – 1, it is about 7% less, when compared with CAC – 2. Even if, CAC – 2 is considered as the alternative to compare with, it is clear that first cost — and also energy cost (shown above) — is not a constraint in decision-making on the choice of CAS.

CAS for Hot Dry Climate

Although, the above study has been made for a warm humid coastal climate typified by Mumbai, the CAS has been applied (abroad) for hot dry areas also with appropriate changes in detailed design.

CAS + TSS (Thermal Storage System)

CAS is often regarded as something, which should necessarily go with TSS in order to be viable and attractive. It will be seen however, from the foregoing, that it is an attractive alternative to CAC even when there is no TSS to prop it. Apart from technical considerations, it is competitive in price and energy consumption is lower. It is therefore attractive and viable on its own.

The same remark applies to TSS also i.e., it is viable and attractive on its own. When the two are combined, additional benefits will accrue. Where 45°F water would have been used, TSS produces 35°F (1.7°C) Ethylene Glycol. This can be provided directly to a CAS instead of inserting an interface, like a plate heat exchanger, to raise it to 45°F to suit CAC. If this is done, the cost of producing brine can be equitably debited to TSS and CAS, making each system, in combination with each other, more viable.

When the beneficial effect of TSS in reducing the installed plant capacity is taken into account, the capacity of CAS is further reduced to half i.e. plant capacity will be only about

40 ton as compared to 118 ton for CAC – 1 and 88 ton for CAC – 2. Inevitably, this will translate to further reductions in first cost and energy cost.

CAS Plants have been gaining in popularity over the past decade in the US and other advanced countries. The earliest TSS installations in this country are about a dozen years old and there are over 30 TSS installations at the present time, including the largest one — the Tidal Park installation at Chennai, which went into stream recently. However, to this writer's knowledge, CAS has not been provided for any project so far either with TSS or on its own.

A partial list of CAS installations is given below :

1. 34 storey Taipei World Trade Centre, Taipei, Taiwan – Office Building.
2. Kouri Corporation, Greenboro, North Carolina, US – Office Building.
3. Public Utilities Operations Centre, Riverside, California, US – Office Building.

Conclusions

With today's emphasis on energy conservation and indoor air quality, there is a clear case for considering CAS, preferably with TSS, for all commercial buildings and office buildings.

CAS benefits and advantages come at no extra cost.

Bibilography

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