Internal latent heat load from the staff and a large outdoor air requirement make this an ideal application for a DOAS

An Introduction to DOAS

Dedicated Outside Air Systems

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HVAC has come a long way. Designers have been con stantly working to improve the system design on various fronts. Efficiency, energy management, indoor air quality, controls, noise reduction, compactness, economics, and environmental impact, have been the key drivers pushing the designer to deliver better and more. All the innovations and design improvements have been built around the "traditional approach" with the cooling coil as our main tool in controlling both temperature and moisture (for cooling and dehumidification) in the conditioned space. System designs have moved to providing better indoor air quality by increasing and having the right mix of re-circulated and outside air, but some questions remain unanswered.

"Are we really successful in controlling both temperature and moisture in the conditioned space in all weather conditions?"

"Are we trying to kill two birds with one stone?"

"Have we built our fort on a foundation which has a fundamental limitation?"

This article provokes you to think and act on some problems, which have been accepted as a "part of the system" for too long. It discusses concerns with the current design methodology and lists some of the possible alternatives.

The article advocates the need to have better and individual control over the key elements of air conditioning i.e. temperature and moisture. With the help of DOAS approach (dedicated outside air systems), one can clearly manage both elements efficiently. The DOAS approach has many routes and information on various DOAS designs has been disseminated in the article, which introduces different designs but does not detail each design from an application point of view.

Finally it is up to the readers to decide whether they are ready to make the paradigm shift

Solving One Problem and Creating Another

In the current work culture, most of us spend almost 80 - 90 % of our lives in conditioned spaces. Research indicates that conditioned spaces can be 10 - 100 times more polluted than outside air. Hence it is important that dilution of the conditioned air is done with adequate amount of outside air. Outside air rates have been clearly defined in the National Building Code of India 2005 and these will be able to improve the conditioned space to an acceptable quality.

This increased amount of ventilation (refer *Table 1*) has definitely solved some IAQ problems, but the inability to maintain the right humidity with our HVAC system design has lead us to other problems. The formation of mold and mildew is a serious dilemma in itself, which is caused by lack of humidity control. The question is "have we traded

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S. No. (1)	Application (2)	Estimated Maximum Occupancy Persons/ 100 m² (3)	Outdoor Air Requirement (Litres per second L/s): (L/s) per person (4)	(L/s)/m² (5)
i)	Commercial dry cleaner	30	15	
ii)	**Food and Beverage**			
	Service	70	10	
	Dinning Rooms	100	10	
	Cafeteria, Fast Food	100	15	
	Bars, Cocktail lounges			
iii)	**Hotels, Motels, Resorts,**			
	Dormitories		15	
	Bedrooms	30	8	
	Lobbies	50	10	
	Conference Rooms	120	8	
	Assembly Rooms	7	10	
	Office Space	60	8	
	Reception Areas	50	10	
	Conference Rooms			
iv)	**Public Spaces**			
	Upper Floors	20		1.00
	Storage Rooms	15		0.75
	Malls and Arcades	20		1.00
	Warehouses	5		0.25
	Smoking Lounge	70	30	
v)	**Theatre**			
	Ticket Booths	60	10	
	Lobbies	150	10	
	Auditorium	150	8	
	Stages, Studios	70	8	
vi)	**Education**			
	Classroom	50	8	
	Music Rooms	50	8	
	Libraries	20	8	
	Auditoriums	150	8	

Table 1: Outdoor air requirement for ventilation of air conditioned areas and commercial facilities (Source - National Building Code of India 2005)

one problem with the other?"

IAQ & RH Control

The benefits of increased ventilation have been clearly established and absorbed by the HVAC industry at large. The health of occupants is of great concern and more and more systems are being designed with the right amount of outside air.

The outside air however while solving this problem poses a great challenge for the HVAC system. The savior of IAQ brings along with it the quandary of high latent load, imposing a heavy load on the HVAC equipment and resulting in high RH inside. Let us examine the load profile of outside air in a tropical country like ours.

Shown in *Figure 1* is the load profile of outside air for the city of Mumbai. The curve defines the load of outside air in terms of the sensible and latent load in tons for the entire year. Clearly one can see that latent load of the city is quite high and is around 78% of the cumulative fresh air load.

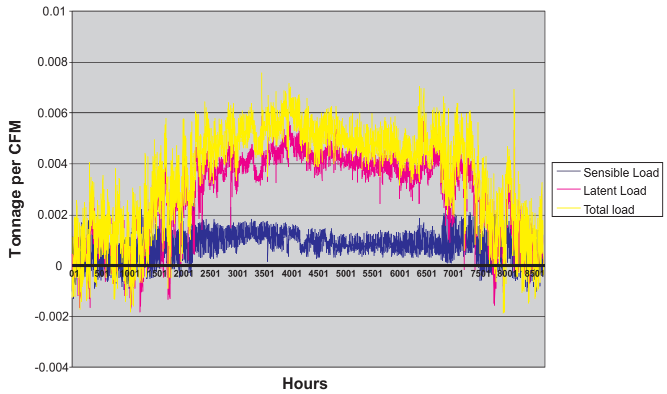

Figure 1: Ventilation Load Index Mumbai (for 1000 cfm)

Similarly if one studies the profile of the cumulative loads (i.e cooling and dehumidification only) for major cities of India one can see that the latent load component of the fresh air is quite high ranging from 60% to 85% (refer *Table 2*)

City	Load per year Ton – hours / SCFM		
Name	Sensible	Latent	Total
Ahmedabad	8.78	16.61	25.39
Amritsar	5.58	13.29	18.87
Bhopal	6.13	10.38	16.51
Chennai	8.6	30.14	38.74
Dibrugarh	3.48	19.55	23.03
Delhi	6.94	14.22	21.16
Guwahati	4.72	23.18	27.9
Hyderabad	7.01	14.58	21.59
Indore	5.74	9.25	14.99
Jaipur	7.49	11.62	19.11
Kolkata	6.85	27.62	34.47
Lucknow	6.42	17.36	23.78
Mangalore	6.64	26.6	33.24
Mumbai	7.38	25.26	32.64
Patna	6.78	20.48	27.26
Pune	4.64	14.84	19.48
Trivandrum	7.68	17.12	24.8
Vizag	7.78	30.72	38.5

Table 2: Ventilation Load Index chart for various cities (per cfm)

With outside air bringing in a high amount of latent energy, RH management becomes difficult. Lack of RH control leads to growth of mold and mildew which leads to various health related issues. Mold releases tiny spores in order to reproduce. These spores then waft through the indoor air and start developing in damp areas. They can cause several problems like rashes, asthma, running nose, respiratory problems including serious diseases like hypersensitivity pneumonites, etc. (refer *Figure 2*)

Latent Loads

If RH control is so critical and important let us examine the latent load profiles in a building. Comparing the sources of the latent load, it is clear that the largest contribution to the latent load component is the outside air. The chart in *Figure 3* clearly shows that almost 50% – 70 % of internal latent

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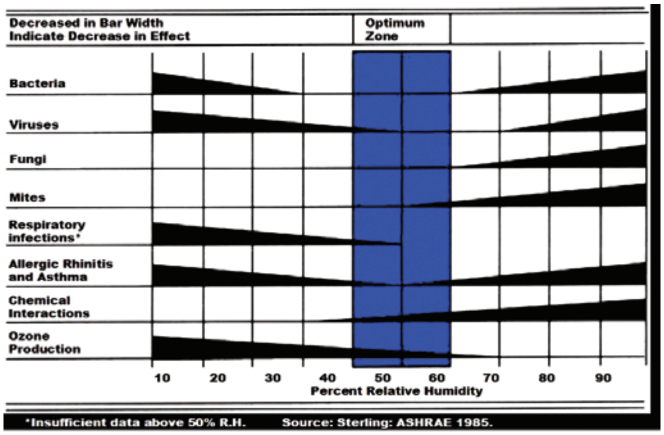

Figure 2 : Safe Relative Humidity Levels
Source: Sterling ASHRAE 1985

load comes from ventilation air.

RH Control Challenge

Why is it so difficult to manage RH? The answer lies in the fact that the sensible and latent loads don't peak at the same time. Hence in moderate weather, the sensible loads are reduced but latent loads remain high. With ventilation air bringing in most of the internal latent load, one needs to study the ability of a conventional cooling system to control RH during moderate weather conditions. A thermostat-driven cooling coil will experience great difficulty in managing the RH in low sensible load periods. i.e. off peak periods of the day or monsoon weather in most of India. The problem is that in moderate weather the outside temperature drops but the moisture level remains high. And with the ambient temperature dropping the sensible loads drop. Hence the return air temperature is quickly achieved thereby triggering the thermostat to switch off the compressor in the constant volume DX cooling system, allowing it to operate only for short periods. As a result the moment the compressor turns off, the coil stops dehumidifying

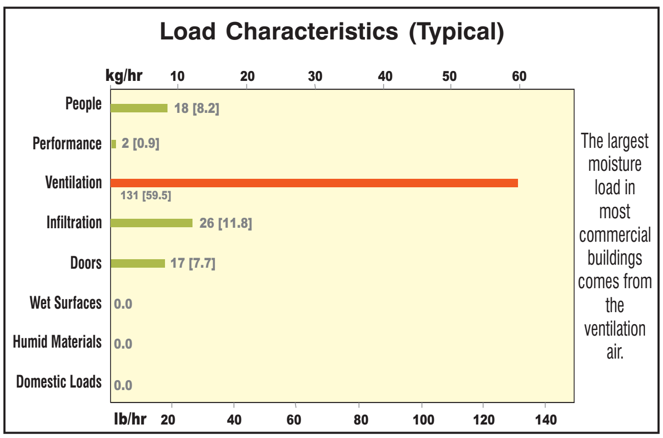

Figure 3 : Latent Load Characteristic

and moisture remaining on its surface re-evaporates back into the supply air. (refer *Figure 4*)

Even in an immaculately designed central plant system, where one does design for very low ADPs and reheat, one faces difficulty in controlling RH during low sensible loads. Such systems do have better RH control, as compared to constant volume, DX cooling systems but are highly energy intensive (involve sub cooling and then reheat) and are increasingly getting banned in many countries.

With moderate weather prevailing during a considerable part of the season during monsoons and throughout the year in many coastal cities, this problem needs immediate attention.

Control Strategies

Traditionally one would immediately talk about a system with low ADP i.e., having low chilled water temperature, high number of rows deep (8 row or deeper) and reheat with active energy.

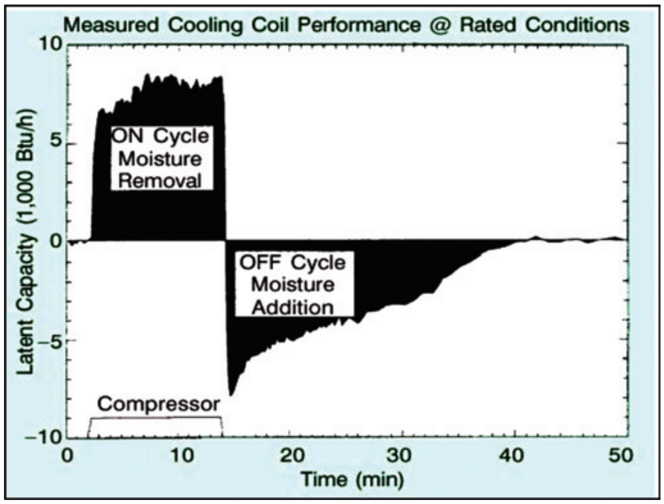

Figure 4: After the compressor shuts off, moisture condensed on the cooling coil re-evaporates. An example of passive humidity moisture control in a 3 ton unit. Source: *Dehumidification Equipment Advances* by Lewis G. Harriman III.

Such systems do help but are highly inefficient and drain a lot of energy. *Figure 5* illustrates the fact that one has to first sub-cool and then add active reheat wasting energy twice.

DOAS Approach

Constant volume, mixed air, HVAC units are generally selected with sufficient cooling capacity to handle dry bulb design and are controlled by a thermostat, which matches the sensible cooling capacity of the coil with the sensible cooling need of the space. But when it is cool and rainy outside, the latent cooling load can approach or even exceed sensible cooling load. To overcome this problem one needs to divide the load into two components i.e.

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'sensible' and 'latent' and handle them separately. This approach commonly referred to as "divide and conquer" deals with both components separately.

As already identified, majority of the internal latent load is coming from the outside air. Hence, it is important that the latent load of this air be handled separately. The DOAS approach works on this principle only. It removes all the latent load being brought by the outside air at the source and processes the same to a very low dew point thereby enabling it to take care of the rest of the internal latent load too.

The internal cooling devices are then limited to sensible cooling only. If one wants to draw an analogy its like making the "naughtiest boy" of the class as the "class monitor".

This approach now opens up a whole new world of innovative designing and helps the designer to maintain the right RH throughout the year irrespective of the weather pattern outside. The IAQ and RH management both get resolved and one is able to overcome all obstacles being experienced by conventional systems.

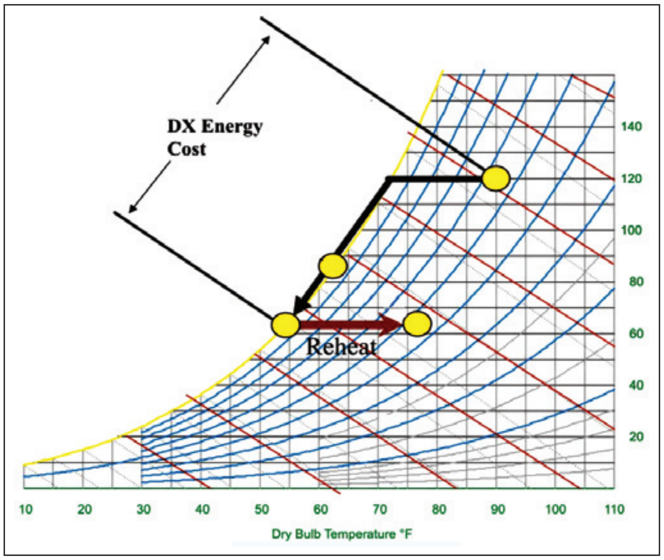

Figure 5 : High Energy of Reheat based system.

The designer can now increase the chilled water temperature feeding the internal air handling units, reduce the row deeps (as ADPs can be increased) and can optimize between the air volume and ADP (thereby chilled water temperature) as one is now not limited by the Sensible Heat Factor (SHF) any longer, to get the maximum energy and space efficiency.

DOAS Technology Option

Various technologies are available in the market today and each one of them carries a few advantages unique to them. No technology is a panacea and each one of them proves superior in a particular application for a particular internal and external load profile. While I will introduce you to these technologies, it is outside the scope of this paper to analyse each technology in detail from an application point of view. To judge the right application one would need a detailed analysis including simulation techniques to compare them with each other and conventional HVAC systems from the first cost and the operating cost perspectives.

The various DOAS technologies available are:

Consider a two storied call center in Mumbai with the following load profile

1)	Peak Wet Bulb temperature with mean coincidental dry bulb (0.4%) (peak enthalpy)	= 93°F DB/82°F WB 149 gr/lb
2)	Inside condition	= 72°F DB/55% RH 65gr/lb
3)	Inside Load pattern	
	GROUND FLOOR (GF)	
	Effective room Sensible Heat	= 451680 Btu /hr
	Effective room Latent Heat	= 98000 Btu/hr
	Occupancy	= 300 Persons
	FIRST FLOOR (FF)	
	Effective room Sensible Heat	= 515832 Btu /hr
	Effective room Latent Heat	= 101000 Btu/hr
	Occupancy	= 325 Persons
4)	Outdoor Air Flows (with 20 cfm per person)	
	GROUND FLOOR (GF)	= 300 x 20 = 6000 cfm
	FIRST FLOOR (FF)	= 325 x 20 = 6500 cfm
5)	Humidity Ratio rise for DOAS to maintain 65 gr/lb inside	
	GROUND FLOOR (GF)	
	Effective room Latent Heat	= 98000 Btu/hr
	Bypassed OA Latent Heat (6000 x (149-65) x 0.68 x 0.12)	= 41126 Btu/hr
	(0.12 - Bypass Factor)	
	Internal Latent Loads W/o OA load	= 56874 Btu/hr
	Humidity Rise DWGF	$= \frac{56874}{0.68 \times 6000} = 13.9$ gr/lb
	FIRST FLOOR (FF)	
	Effective room Latent Heat	= 101000 Btu/hr
	Bypassed OA Latent Heat (6500 x (149-65) x 0.68 x 0.12)	= 44554 Btu/hr
	Internal Latent Loads W/o OA load	= 56446 Btu/hr
	Humidity Rise DWFF	$= \frac{56446}{0.68 \times 6500} = 12.8$ gr/lb
	Hence we choose DW Selected	= 13.9 gr/lb
6)	Supply air dew point (DOAS)	
	W supply	= W inside - W Selected = 65 - 13.9 = 51.1 gr/lb
	T supply	= 49°F Dew point
7)	Supply air Temperature (DOAS)	= 70°F

Hence one can design a Dedicated Outside Air System with 70°F DB/ 49°F DP as supply air condition and internal AHU's will work as sensible cooling devices only.

Sample Calculation for a DOAS.

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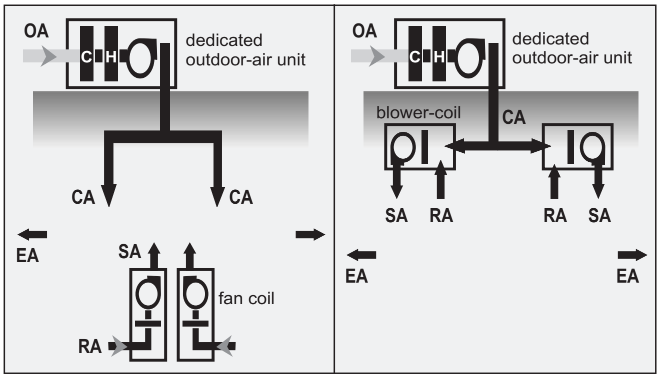

Figure 6 : Conditioned OA.
(Source : The ABC's of DOAS by Wayne Morris)

Option I - Rotary passive desiccant air-to-air heat exchanger coupled with dehumidification coil.

Option II - Rotary passive desiccant air-to-air heat exchanger coupled with dehumidification coil and sensible air to air heat exchanger.

Option III - Active desiccant dehumidification wheel (with condenser heat reactivation) coupled with DX cooling coil.

Option IV- Rotary passive desiccant air-to-air heat exchanger coupled with dehumidification coil and passive desiccant dehumidification wheel.

Lets examine each option now.

Option I - Rotary passive desiccant heat exchanger with coil. (Refer *Figure 7*).

This option gives high efficiency heat recovery and reduces the total installed tonnage of the HVAC system. Since the recovery reduces both latent and sensible load of the outside air (the recoveries can be as high as 85%) and the dehumidification coil reduces the dew point to almost 50°F, this approach is most widely used and is highly cost effective and paybacks are often negative.

The benefits of this option are :

- Installed tonnage reduction
- Lower power consumption of the installed HVAC system

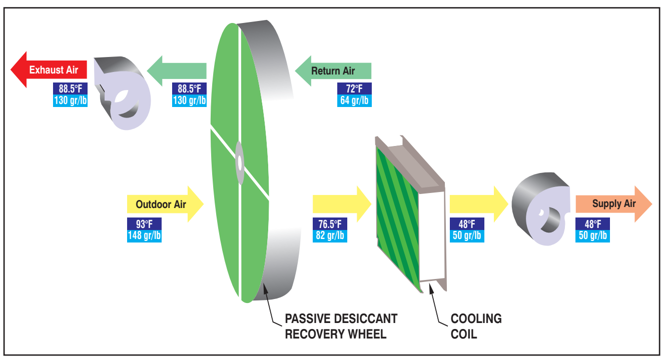

Figure 7 : Option I

- Higher ADPs of sensible cooling devices hence lower row deeps (lower pressure drop) and higher CHW temp of main chiller.
- Better performance of the chiller in terms of ikW/TR due to higher CHW temperature

Option II – Rotary passive desiccant heat exchanger with coil and rotary sensible heat exchanger. (Refer *Figure* 8).

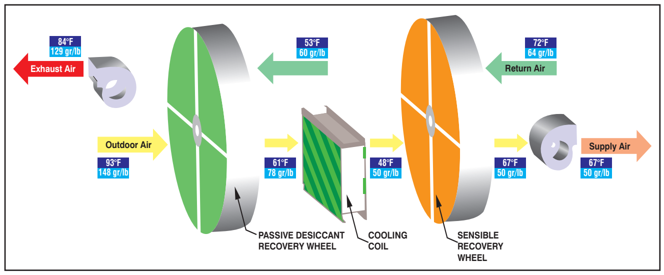

Figure 8 : Option II

This option is designed keeping in mind the following objectives:

- Always provide conditioned air that is drier than the air in the space
- Deliver cold conditioned air whenever possible, and use recovered energy to reheat during mild weather.
- Select equipment to limit indoor relative humidity to 55 % in all seasons

This option has all the features of Option I and in addition supplies air at almost room temperature. The advantage here lies in the fact that during moderate weather i.e. when outside ambient temperature is low but latent load is high (typically monsoons weather), the option I too can have difficulty in handling the

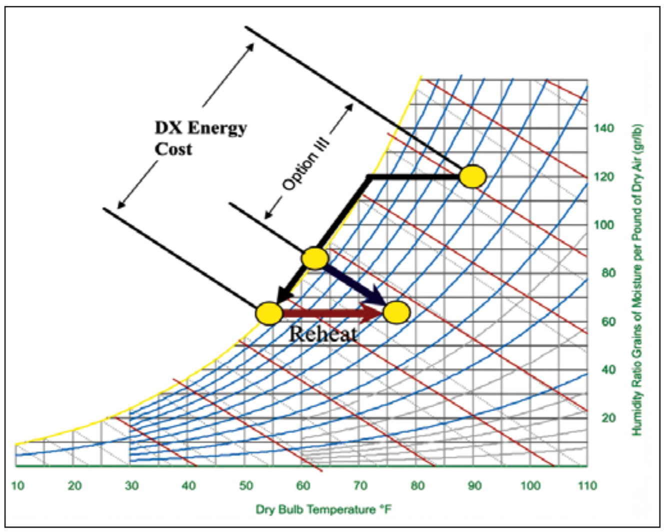

Figure 9 : Psychrometrics of Option III

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RH.

This option supplies air at almost room temperature with lower dew point than the space, hence it can continue to control the moisture without the risk of lowering the temperature.

The benefits of this option are :

- Possibility of obtaining almost 80% of LEED points.
- Good RH control in all the seasons

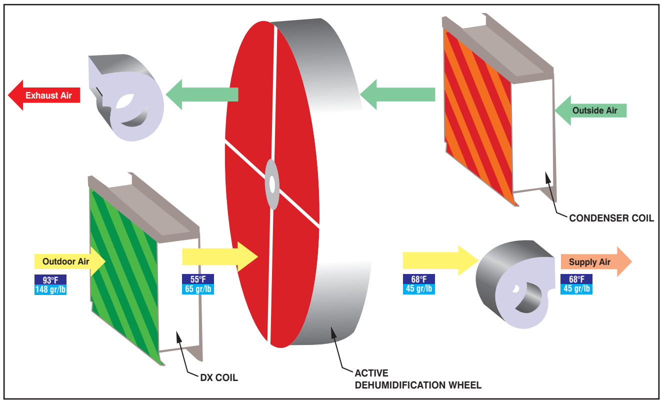

Figure 10 : Option III

- Reduced installed tonnage and lower power consumption of HVAC system.
- Internal sensible cooling devices have higher CHW, lower ADPs resulting in reduced pressure drops and better ikW/TR for chiller.

Option III - Active desiccant dehumidification wheel (with condenser heat reactivation) coupled with DX cooling coil. (Refer *Figures 9 & 10*).

This option combines the benefits of desiccant dehumidification with cooling of the DX air conditioners. Contrary to the first two options, this approach uses the desiccant wheel to remove moisture and lower the dew point of the supply air instead of using a cooling coil.

The reactivation of the desiccant wheel is undertaken by recycled heat from the DX condenser air.

The benefits of this option are :

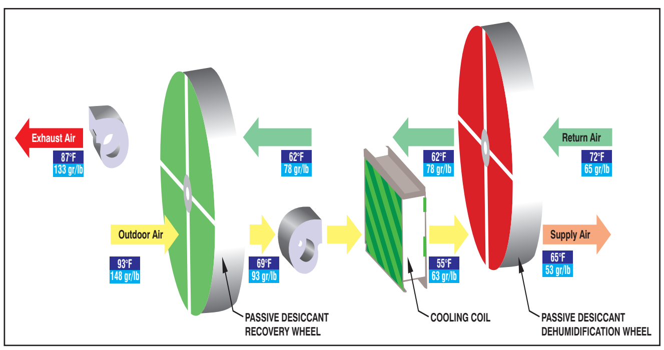

Figure 11 : Option IV

- Meets ASHRAE Standard 90.1 requirements.
- COP 65% more than a conventional DX system with reheat.
- Uses recycled heat from DX system for reactivation.
- No active reheat required.
- Maintains RH control in all the seasons (including for areas having high internal latent loads)

Option IV - Rotary passive desiccant heat exchanger with cooling coil and passive desiccant dehumidification wheel. (Refer *Figure 11*).

This approach utilizes the strengths of passive total energy recovery, conventional cooling and a new type of desiccant rotor, the passive dehumidification wheel. The ability of this system lies in the fact that it optimizes the moisture removal between the cooling coil and the desiccant wheel without the need of active re - activation. The passive desiccant wheel removes moisture from saturated air stream in an highly energy efficient manner.

The benefits of this option are :

- Extremely good RH control in all seasons
- High energy efficiency
- Lower dew point of supply than the other three options.
- Versatile and adjusts well to varying climate
- Installed tonnage reduction for the HVAC system.

Parallel Sensible Cooling Options

When using the DOAS approach the internal cooling devices work only as sensible cooling devices. The options available for internal cooling / heating are:

- Unitary equipment
- Terminal AHU / FCU
- VAV system
- Radiant cooling panels

Each one of these has its own distinct advantages for type of zoning required for specified HVAC application.

Conclusion

The indoor air quality requirement of higher ventilation rates along with proper RH control and energy management will push the HVAC designer to the use of "dedicated outside air systems" in the near future. DOAS holds a lot of promise with its ability to maintain the right humidity in all weather conditions. The "divide and conquer" approach definitely allows the designer to have better management of the two key elements of air

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conditioning i.e. temperature and moisture. The original definition of air conditioning can now be met in an energy efficient manner.

The DOAS has already proved itself with high potential of energy savings in nearly all applications and weather profiles. However the benefit of Options-II, III and IV over the first option in terms of energy saving is seen in a few applications only. Otherwise, from the energy point of view Option-I has come out to be the most cost effective.

However in RH control the last three options discussed have performed better for a wide variety of applications and weather profiles. To clearly state that a particular option is the best solution would be a meaningless statement as proper simulation exercises need to be conducted on a few key applications for a few weather profiles and "first cost + operating cost" matrix tabulation, giving due consideration to the importance of RH control. Some studies have indicated that the installed first cost of DOAS approach is lower than a conventional system for certain applications. A paradigm shift is taking place and designers are now actively considering these options to weed out the "traditional problems". In the words of Albert Einstein, *Science is nothing more than a refinement of everyday thinking.*

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