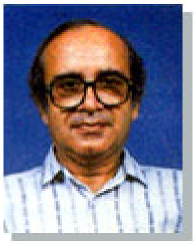
AIR CONDITIONING AND REFRIGERATION
Journal
The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Issue : January-March 1999

Dx Air Conditioning For Office Buildings



M.H. Lulla

Consultant, Chennai

A 1966 engineering graduate from Annamalai University, he worked for 8 years with a contracting company before setting up practise as an HVAC consultant. Teaches at the School of Architecture, Chennai and is associated with an engineering college for academic work.

An integral part of urban modern day living for most individuals is working in an office. An office as conceived in the British Raj was an enclosure of magnanimous size with 4 legged furniture of wood qualifying for names of pieces like tables and chairs. The present day office has come a long way - open plan layouts - modular furniture and built in services like conferencing, computers and communication facilities have become a hall mark of efficiency. Air conditioning has made this possible and affords levels of planning which permit economics to be made by more and more compact layouts.

These trappings for an office with air conditioning as the central feature are a logical development founded on extensive research. Productivity gains as large as 15% have been clocked if environmental factors are designed and controlled well. In terms of real money American research can be quoted as saying that 3% improvement in productivity works out to an annual saving of 3 million dollars for an office of 5,00,000 sq.ft. The cost of salaries being 8 to 13 times the cost per sq.ft. (Occupancy being pegged at 150 sq.ft. Per person)

DX Systems

Facts and figures like the above along with a practical awareness of the same by sheer gut feel have funnelled the need of office air-conditioning. This need is fuelled more and more by intensive use of office facilities or extended hours. One of the most economical ways of effecting air-conditioning in offices is by DX systems. A DX system is founded on the successful use of the Vapour Compression Cycle. A DX system is a system in which the refrigerant expands directly inside a coil, in the main air stream itself to effect the cooling on the air.

By the book one may say that a DX system is one which uses a DX evaporator. A DX evaporator is one with tubes which are so arranged that refrigerant passes through the inside of tubes. There may be a single tube circuit or there may be any number of parallel-tube, equal-load circuits. The number of parallel circuits may be the same throughout the length of the evaporator or it may vary. For example, refrigerant may even one end of each of twelve tubes and continue in the twelve parallel circuit until they all join the common suction line or it may enter 8 tubes and, on leaving those, branch to 12 tubes which branch to 16 tubes which finally terminate in the common suction line.

This type of evaporator may be cross feed, as in a coil having horizontal air flow. It may be up or down feed in the case where the fluid to be cooled passes up or down through the evaporator. Upfeed is usually the most desirable. (The direction of flow, upfeed or downfeed is not a criteria which determines whether an evaporator is dry expansion or flooded.)

The refrigerant enters one end of each of the evaporator circuits and all of the liquid becomes a gas before reaching the end of its circuit. It is this characteristic of the evaporator which makes it the direct expansion type (also called dry type).

A direct expansion evaporator is usually fed by a superheat control (often called thermostatic) expansion valve. In special cases, a constant pressure valve, a capillary tube or even a high side float may be used. Except for many small evaporators using capillary tubes, the superheats control valve is used almost exclusively.

Table 1 DX vs Chilled Water

Type	Sat. suction temp (° F)	Sat.discharge temp (° F)	Capacity (TR)	hp	Bhp/TR
DX	45	105	123	104	0.845

Chilled Water	35	105	99	103	1.040

For a 100 ton system the saving in power when translated into real money value per annum will be:-
(1.04 - 0.84) x 100 x 0.746 x 10 x 300 x 0.5 x 4/ - Rs. 89,520/-
(Based on 10 hours/day use, 300 working days a year, Rs. 4/- per unit, an annual diversity figure of 0.5 and ignoring motor efficiency)

Advantages of a DX System

A DX system is the most basic form of cooling and offers the following advantages:

- **Low Operating Cost:** By virtue of the refrigerant cooling the air directly the compressor of the system will operate at about 10 to 12 deg. F. Lower than the desired ADP temperature. In a chilled water system it would be necessary for chilled water to be 10 to 12 deg. F, lower than the ADP and the compressor suction will then be another 10 to 12 deg. F, lower than the desired chilled water temperature. Typical figures for a 100 ton unit are shown in **Table 1**.
  It is obvious from these figures that the compressor when working on a DX job gives a good 20% in border line cases this could lead to a large saving if one uses a one size smaller compressor for the DX job.
- **Low Capital Cost:** A DX system has the least number of components due to the air being cooled by the refrigerant directly. As such its cost is low. Apart from this by virtue of operating at an elevated suction temperature the compressor capacity is higher - thus its price per ton gets reduced. A detailed pricing for the total saving can be seen from the example at the end.

Types of DX Systems

DX systems are of two types: central or packaged / split.

The central DX system is generally a custom engineered system. Components which make up the system are large and they are all site assembled to form the central system. Generally, one might say that a minimum size of 30-40 tons per compressor is required to put together an economical central system.

The packaged air conditioners or split type AC units are factory made and generally smaller, with the compressor size not exceeding 15 TR. Most unit manufacturers do not put in compressors larger than 7.5 TR, in factory made equipment. The packaged air conditioner is generally the term used for equipment where the compressor, condenser, cooling coil and its fan are put together in a floor mounted cabinet (in an air cooled version of the packaged unit the condenser will normally not be in he main cabinet). In the split air conditioner the compressor and condenser form a condensing unit which is kept in the open and is remote located from the indoor unit comprising of the cooling coil and its blower. The indoor unit is generally suitable for ceiling suspension.

A simple way to distinguish between the two systems, would be by size. One may say that packaged / split units have individual capacities from 5 to 15 TR each. Such units may be put together in multiples to form a cooling system of capacity, say, up to 40-50 TR. Beyond such sizes one can consider using central DX systems.

Water Cooled or Air Cooled

Any ac system is just a pump - a heat pump. It pumps our heat from the space to be cooled and rejects it into an adjacent ambient space. This heat rejection can be through water or air. Both the central and packaged systems can be water cooled or air cooled. The water cooled systems reject condenser heat into water which is re-circulated through their condensers and a cooling tower. The recirculation rate being 4 gpm/TR. This recirculation results in.evaporation and bleed losses which call for make up water. The make up water rate can be taken as 4 gph/TR. Air cooled systems on the other hand do not need water. In such machines heat rejection is to the atmosphere directly through an air cooled condenser. The air cooled condenser have to be generally kept very close to the evaporator units and for smaller sized equipment the length cannot exceed 15 feet whereas for larger systems it may go upto 3 to 4 times this figure. In the case of water cooled equipment the cooling tower which is the final heat rejection point may virtually be at any distance from the cooling equipment.

The economics of a water cooled system vs an air cooled system shown in **Table 2** can be summarized as under:

- At peak load conditions air cooled machines consume over 30% more power than water cooled units.
- Compressor capacity drops by over 10% for air cooled machines compared to water cooled.
- The paucity of good quality soft water makes it imperative to opt for air cooled systems in most installations.

Table 2 Water vs Air Cooled

Type	Sat. suction temp (° F)	Sat.discharge temp (° F)	Compressor Capacity (TR)	Bhp	Bhp/TR
Water Cooled	40	110	82	82.0	1.00
Air Cooled	40	130	69	94.7	1.37

For a 100 ton plant:
The increased annual power cost of an air cooled system equals:
(1.37 - 1.00) x 100 x 0.746 x 10 x 300 x 4/- x 0.5 or Rs. 1,65,000/-
(In actual practice the above figure will come down by half because the off peak disparity between air cooled and water cooled head pressures is lower. Motor efficiency has been ignored).
Annual cost of water for a water cooled system at, say, Rs.300/- per 1200 gallons equals :

$$\frac{100 \times 4 \times 10 \times 300 \times 0.5}{1200} = \text{Rs.}1{,}50{,}000\ /\text{-}$$

Variations in System Capacity

It is worthwhile to note that both the operating conditions and the capacity of a refrigerating system change as the load on the system changes. When the load on the system is heavy and the space temperature is high, the actual evaporator temperature difference (Δt) will be somewhat larger than the design evaporator (Δt) and the capacity of the evaporator will be greater than the design evaporator capacity. Because of the higher evaporator capacity, the suction temperature will also be higher so that equilibrium is maintained between the vaporising and condensing sections of the system. Hence, under heavy load conditions, the system operating conditions are somewhat higher than the average design conditions and the system capacity is somewhat greater than the average design capacity. Obviously, the horsepower requirements of the compressor are greatest at this peak load condition and the compressor driver must be selected to have sufficient horsepower to meet these requirements.

Conversely, when the load on the system is light, the space temperature will be lower than the average design space temperature, the evaporator Dt will be less than the design Dt and the suction temperature will be lower than the design suction temperature. Therefore, the system operating conditions will be somewhat lower than the average design operating conditions and the system capacity will be somewhat less than the average design capacity.

The system passes through a complete series of operating conditions and capacities, the operating conditions and capacity being highest when the space temperature is highest, and lowest when the space temperature is lowest. However, during most of the running cycle, a well-designed system will operate very nearly at the design conditions.

Capacity Control

The importance of balancing the system capacity with the systems load cannot be over-emphasised. Any time the system capacity deviates considerably from the system load, unsatisfactory operating conditions will result. Good practice requires that the system be designed to have a capacity equal to or slightly in excess of the average maximum sustained load. This is done so that the system will have sufficient capacity to maintain the temperature and humidity at the desired level during periods of peak loading. Obviously, as the cooling load decreases, there is a tendency for the system to become oversized in relation to the load.

In applications where the changes in the average system load are not great, capacity control is adequately accomplished by cycling the system on and off. In such a case, assuming that the cycling controls are properly adjusted, the relative length of on and off cycles will vary with the load on the system during periods when the load is heavy, "on" cycles will be long and "off" cycles will be short whereas during periods when the load is light, "on" cycles will be short and "off" cycle will be long. Naturally, the degree of variation in the length of the on and of cycles well depend on the degree of load fluctuation. However, since the system must always be designed to have sufficient capacity to handle the maximum load, when the changes in the system load are substantial, it is evident that the system will be considerably oversized when the load is at a minimum. A system which is oversized for the load will usually prove to be as unsatisfactory as one that is undersized for the load. When the system is undersized for the load, the running time will be excessive, the space temperature will be high for extended periods. On the other hand, where the system is oversized for the load, the off cycle will be too long and the equipment running time will be insufficient to move the required amount of moisture from the space.

For this reason, when changes in the system load are substantial, it is usually necessary to provide some means of automatically (or manually) varying the capacity of the system other than by cycling the system on and off. This is true also of large installations where the size of the equipment renders cycling the system on and off impractical.

There are many methods of bringing the refrigerating capacity into balance with the refrigerating load. Naturally, the most suitable method in any one case will depend upon the conditions and requirements of the installation itself. Some installations require only one or two steps of capacity control, whereas other require a number of steps.

In some installations, the refrigerating capacity of the system is adequately controlled by controlling the capacity of the compressor only. Since the flow are of the refrigerant must be the same in all components, any change in the capacity of any one component will automatically result in a similar adjustment in the capacity of all the other components. Therefore, increasing or decreasing the capacity of the compressor will, in effect, increase or decrease the capacity of the entire system. However, it is important to note that with this method of capacity control the operating conditions of the system will change as the capacity of the system changes.

Where it is desired to vary the capacity of the system without allowing the operating conditions of the system to change, it is necessary to control both the evaporator capacity and the compressor capacity directly.

Some of the more common methods of controlling evaporator and compressor capacities are considered in the following sections.

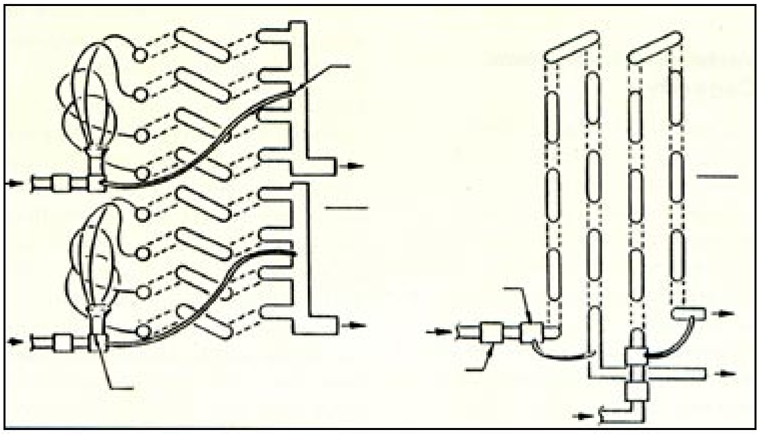


Figure 1: DX coil with face and row control arrangement

Evaporator Capacity Control

Probably the most effective method of providing evaporator capacity control is to divide the evaporator into several separate sections or circuits which are individually controlled so that one or more sections or circuits can be cycled out as the load decreases. Using this method, any percentage of the evaporator capacity can be cycled out in any desired number of steps. The number and size of he individual evaporator sections depends on the number of steps of capacity desired and the percent change in capacity required per step, respectively. The arrangement of the evaporator sections or circuiting depends on the relationship of the sensible load to the total load at the various load conditions. Basically, two circuit arrangements are possible. Evaporator circuiting can be arranged to provide either "face" control or "depth" control, or both. When "face" control is used, the "sensible heat ratio". On the other hand, "depth control always changes the sensible heat ratio. As a general rule, the more depth the evaporator has the greater is its latent cooling (moisture removal) capacity. Hence as one or more rows of the evaporator are cycled out, the sensible heat ratio increases. See **Table 3**.

Table 3 Progressive Loading per row DX coil in the direction of air flow

	Approximate percentage of total capacity by rows							
Rows deep	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2	55	100						
3	40	73	100					
4	33	60	82	100				
5	29	52	71	87	100			
6	26	47	60	78	90	100		
7	24	43	58	70	81	91	100	
8	21	39	53	65	76	85	93	100

Another common method of varying the evaporator capacity is to vary the amount of air circulated over the evaporator through the use of "face" or "face-and-by-pass" dampers. Variable speed blowers can also be used for thus purpose. Also in some instances, dampers and multi-speed blowers are used together in order to provide the desired balance.

In nearly all cases, application of any of the forgetting methods of evaporator capacity control will necessitate simultaneous control of compressor capacity.

Compressor Capacity Control

There are a number of different methods of controlling the capacity of reciprocating compressors. One method, already mentioned, is to vary the speed of the compressor by varying the speed of the compressor driver. When an engine or turbine is employed to drive the compressor, the compressor capacity can be modulated over a wide range by governor control of the compressor drive.

When an electric motor drives the compressor, only two speeds (1500 and 750 rpm) are usually available so that the compressor operates either at full capacity or at 50% capacity.

Capacity control of multi cylinder compressors is frequently obtained by "unloading" one or more cylinders so that they become ineffective.

In addition to providing capacity control, cylinder unloaders of all types are used to unload the compressor cylinders during compressor start-up so that the compressor starts in an unloaded condition, thereby reducing the inrush current demand.

When any of the capacity control methods described thus far are used, the horsepower requirements of the compressor decrease as the capacity decreases, although not in the same proportions. Hermetic compressors used in packaged or split ACs do not have any form of inbuilt capacity control. Semi-hermetic compressors however, do have capacity control available but are not used in Indian built packaged units because of higher cost.

Multiple-System Capacity Control

Another method o controlling capacity is to employ two or more separate systems. The evaporators for the separate systems may be in the same housing and air stream or they may be in separate housings and air streams. In either case, separate compressors and condensers are used, although in some instances the condensers may be in a common housing.

This method of capacity control is well suited to installations in office air conditioning where generally two steps of capacity control are adequate. The use of two or more separate systems has the added advantage of providing a certain amount of insurance against losses accruing from equipment failure. Should one system become inoperative, the other can usually hold the load until repairs can be made.

Refrigerant piping

While putting together central DX systems art site, the single largest feature which will require attention from the designer is the refrigerant piping. Many pages have been written on how such systems can be piped and the use of traps and loops clearly spelt out. One must remember that loops and traps are generally of use only to control lubricating oil flow and are not to be used to protect compressors from liquid slugging. If one were to generalise one might say that vertical lines with refrigerant should not exceed three or flour floors. Beyond such heights it becomes uneconomical because of loss of capacity due to pressure drop.

A multiple compressor installation can be piped to have common piping for all the compressors, say 2 or 3 at the most. While installing a common system with multiple compressors it is necessary to plan for liberally sized equalizers on the compressors it is necessary to plan for liberally sized equalizers on the compressor lines to ensure that no compressor crankcase is starved of oil. Some designers are allergic to putting compressors in parallel. Such an allergy can be overcome by piping the compressors individually to separate coils - one each for each zone as in the sketch in **Fig. 2** This kind of "cross piping" in a single AHU gives the system the advantage of being able to follow load variations better and have some flexibility in the case of a compressor failure.

Vibration

Use of a DX system in an office building pr-supposes that the structure will have generally more mechanical equipment, and this equipment would be spread out all over the structure and in most cases it will be adjacent to critical areas. In such a situation vibration is another feature which must be taken care of. Reciprocating compressors located on a building floor present problems of vibration isolation to prevent transmission and telegraphing of this motion to the occupied portions of the building. Small multi cylinder compressors do not create the same situations large compressors of slower speed. Several types of vibration-absorbing bases and foundation are available, each engineered to the particular type of installation. Specialists in vibration control should be consulted.

Photo 1: Reserve Bank of India, Cochin

It is not costly to isolate a small compressor and the same type of isolation would generally be used irrespective of the equipment location. Large units require spring supported floating structural sub bases which in turn must be properly supported by the building. In some cases, weight must be incorporated in the base to absorb unbalanced forces.

It is desirable to isolate interconnecting piping from the building structure by the use of isolation type pipe hangers and flexible seamless tube type connections at the equipment.

Today excellent rubber-in-shear or spring based vibration isolators are available and if these are selected and sourced properly, all vibration problems can be avoided. Generally for compressors running at 1450 rpm a static defection of 15 mm is a must for the isolator.

Higher rpm equipment requires smaller deflection and lower rpms call for greater static deflection.

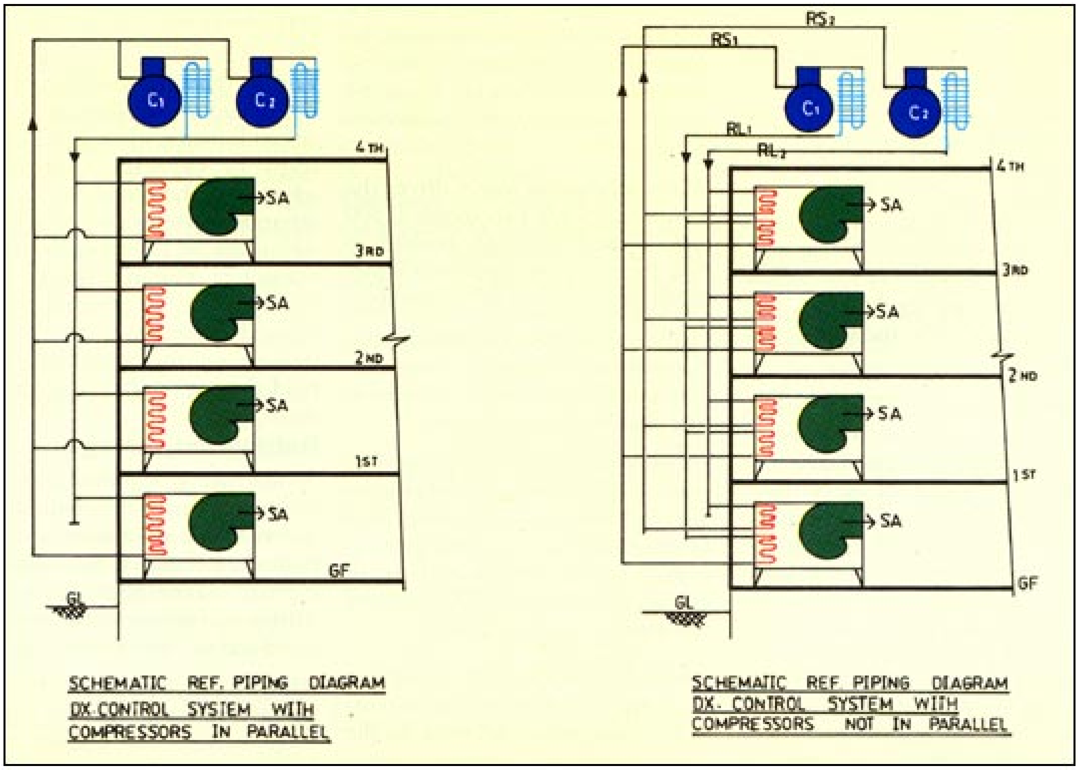


Figure 2: Two principle ways of piping a central DX system

Table 4 Cost Comparison Between 120 ton Central DX and Chilled Water Plant

Item	Chilled Water system (Rs.)	DX System (Rs.)
Compressor	3,00,000/-	3,00,000/-
Condenser	2,70,000/-	2,50,000/-
Chiller	3,00,000/-	---
Coils(Chilled water/DX)	1,80,000/-	2,00,000/-
Ref.pipes and refrigerant	1,00,000/-	2,50,000/-
Cooling tower	2,00,000/-	2,00,000/-
CDs pump	50,000/-	50,000/-
CDs piping	2,00,000/-	2,00,000/-
Chiller pumps	50,000/-	-----
Chiller piping	3,00,000/-	-----
AHUs	2,00,000/-	2,00,000/-
Ducting, grills and diffusers	4,00,000/-	4,00,000/-
Switch board	1,10,000/-	1,00,000/-
Cabling	60,000/-	50,000/-
Plant room	same	same
AHU room	same	same
Total	27,20,000/-	22,00,000/-

OPERATING COST Likely to be 0.1 kW/tr Less for the DX plant	Datum	36,000/- p a.
Saving in power cost = 0.1 x 120 x 10 x 300 x 0.5 x 2/- = Rs. 36,000/-		
If one were to capitalize the above saving of Rs. 36,000/- per annum even at an 18% rate - The answer would be $\frac{36000}{0.8}$ or Rs.2,00,000 /- (*2 lakhs*)		
In other words the DX plant is 5.2 + 2.0 - 7.2 lakhs lower in cost than the chilled water plant.		

Some Examples:

The Reserve Bank of India, Cochin is a typical RCC frame structure. The building is a simple multi-story office building. The building is a four storey structure with each floor having approximately 5000sq.ft. of office space. The total cooling load is 120 ton. The RBI has been building such air-conditioned spaces at regular intervals. All such buildings had been fitted with chilled water systems. A central chilled water system had been originally proposed, for the Cochin building as well. An analysis of cost revealed that a lot of money was being spent on the chillers and allied equipment. With a view to restrict cost without diluting design criteria a search for alternate systems was initiated.

The compact layout and single owner usage prompted consideration of the central DX system. A cost analysis of the two ac systems viz., chilled water and DX was made and results are given in **Table 4**.

Photo 2: Data Software & Research Centre, Chennai

Photo 3: Air cooled condensing units mounted on a special RCC platform

Equipment for this building is schematically shown in **Figure 3**.

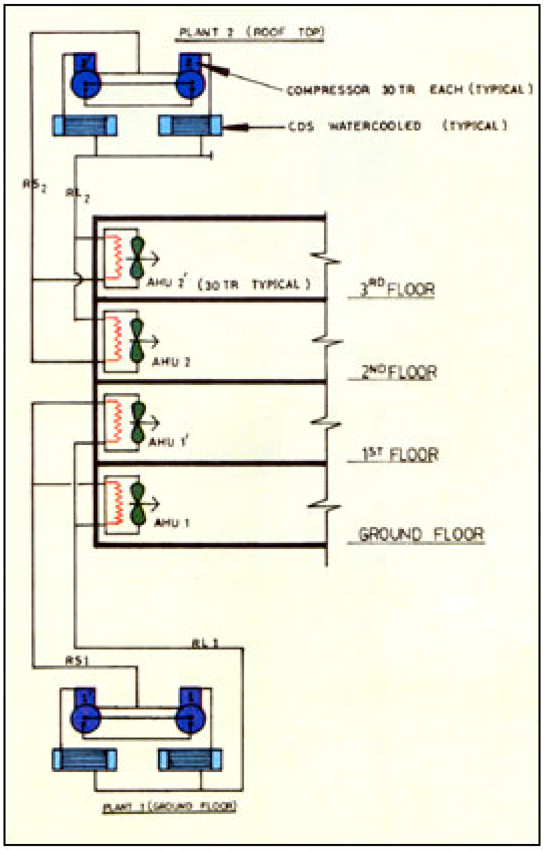


Fig 3: Schematic piping diagram – RBI Cochin

The Data Software and Research Centre (DSRC) on Pycrofts Garden Road, Chennai has five floors air-conditioned with multiple split units. Each floor is 4000 sq.ft/ and requires 20 tons of cooling.

Each floor has been divided into tow equal halves and has four, 5 TR split units, two for the front half and two for the rear half of each floor. The top floor has its ceiling exposed to sun and larger fenestration. Additional cooling for the floor has been installed by using 7 ½ TR units in place of 5 TR units.

Even to a very casual reader it must be obvious that the buildings in the two real life examples are similar. Why then do they have two vastly different systems? **Table 5** explains.

Table 5 Features of the Two Types of DX System

Attribute	**Central system (RBI Cochin)**	**Split units (DSRC Chennai)**
System Ownership	One owner and must be purchased at one time	Multiple owners can buy their own plants.
Capital cost	Rest with the sole owner	Each owner is responsible
Power and operating costs	Are billed as single whole and must be shared by all users	Each zonal plant can have an electric meter fitted on its power mains - and

	on some basis like a per sq.ft.rate. This is sometimes problematic	there after each owner pays for his usage directly.
Plant life	Generally 15 to 20 years	Generally 10 to 12 years
Working hours	Must be the same. The full plant is 'on' or 'off' and the entire building will be fully cooled or not at all	Can be diverse, as every zone is independent. Each zone can have diverse hours of usage as required by individual owner
Impact of the ac system on the building elevation	Minimal, as the heat rejection equipment is centrally located, generally on the roof top	Facade is marred. Since heat rejection equipment, like air cooled condensers must be close to the indoor units, making it necessary for their placement on almost every Floor, exposed to free air Movement. (water cooled Packaged units can be an exception)
Plant operator	Required for at least 2 hours/day	Can be dispensed with, after some minor automation
Plant maintenance	Generally 1 man day per week	Generally 1 man day per Week
Capital cost/tr (in Rs.)	30,000/- to 40,000/-	30,000/-
Minimum total system size for economy	80 - 100 TR (or 15,000 to 20000sq.ft.)	10 - 15 TR (or 1500 to 2000 sq.ft)
Maximum size of system configuration for effective usage.	2 x 125 - 250 TR	3 x 15 = 45 TR (OR) 6 x 7.5 = 45 TR

Disadvantages of a DX System

A careful reading of the above would lead one to formulate a listing of the disadvantages of a DX system. These are:

- As the system has a larger spread, the refrigerant pipes traverse long lengths - hence their pressure testing and protection are critical.
- One cannot have a zone within a zone. As an example in a general office, air conditioned by a DX system - if there is a cabin or two - these cabins cannot have individual independent controls.
- The refrigerant expands directly in the path of the cooling air and hence its choice has to be limited to those which are benign.
- In case there is one small area, say a server room, which needs 24 hour AC then indifference to this need it becomes necessary to run the full AC system

Newer technology has found ways to combat the above weaknesses if not fully at least substantially.

- Pipe material and fittings selected carefully, laid expertly and tested to a stringent level reduce the chances of a leak.
- Variable air volume components can be fitted on to DX systems thus affording good control of conditions within a zone. Generally such a fitment on the whole system means a large increase in cost. In a limited mode, like for instance just one cabin to be zoned out in a full floor - one can install a VAV diffuser for the cabin. Such a device has a motorised damper fitted on the air outlet and the damper operates automatically in response to a thermostat. In other words the diffuser admits or restricts supply air to the cabin in response to the command of a thermostat. Such devices cost about Rs.15,000/- for a 400 cfm size diffuser.
- For small areas within full scale offices like tele-communication rooms or server / computer rooms, where it is necessary to have 24 hour air conditioning - it is possible to have independent split, ancillary AC units exclusively for these areas. These ancillary units can be switched on after office hours. Today one can buy packaged or split units which are fitted with high EER scroll compressors and such units can handle long lengths of piping even upto 100 feet and are fitted with pump in the drain pan so that disposal of the coil condensate also can be arranged with ease.

Conclusion

There is an increasing demand for office space. Modern offices are smaller, compact and filled with a lot of service needs when compared to the older, classical office.

Air conditioning is central to the success of such office planning Ducted DX systems are an economical way of airconditioning such offices. Offices as small as been a thousand sq.ft. Can use split / packaged units. Such units when used in multiple can air condition offices upto a few thousand sq.ft. When the total office space to be air conditioned is , say, 15,000 to 20.000 sq.ft. And does not need excess compartmentalisation then one can use a central DX system. Costs will be nearly comparable to the figure indicated above but the system will be more rugged and "centralised". In case there are one or two vital rooms in these large spaces which need air-conditioning over extended hours, then one can use additional ancillary units for air conditioning such spaces after office hours.