Selection Tips for Air Conditioning Systems

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SELECTION TIPS FOR AIR-CONDITIONING COOLING SYSTEMS

Air conditioning is a combined process that performs many functions simultaneously. It conditions the air, provides heating and cooling, controls and maintains the temperature, and humidity, ensures air movement, air cleanliness, sound level, and pressure differential in a space within predetermined limits for the comfort and health of the occupants. A cooling system is a part of a heating, ventilation and air-conditioning (HVAC) system that provides space cooling.

This course discusses the characteristics of an ideal cooling system for diverse applications. The course is divided in three parts:

Part I Description of Cooling Systems

Part II Key Factors in Selection of Cooling Systems

Part III Key Factors Determining Heat Rejection Systems

PART – I DESCRIPTION OF COOLING SYSTEMS

There are literally dozen or hundred of ways in which basic HVAC components may be assembled into systems but there are **two** basic configurations in which the refrigerant cycle is applied. Both have to do with how the "cooling effect" is supplied to the desired location.

Direct expansion type or DX type is the first configuration, where the air is directly cooled from the refrigerant; therefore the cooling coil is filled with refrigerant. These cooling systems are widely used in small to medium sized buildings. For larger and more complex applications, a secondary cooling medium is used to deliver cooling to one or more locations needing it. This is accomplished by utilizing the chiller to cool the water, which in turn is pumped to the cooling coil(s). The heat flow path is from the space to the chilled water to the refrigerant to the atmosphere.

Direct Expansion (DX) systems

In direct expansion (DX) systems, the air is cooled with direct exchange of heat with refrigerant passing through the tubes of the finned cooling coil. A basic DX system comprises of a hermetic sealed or open compressor/s, evaporator (cooling coil fabricated out of copper tubes and aluminum fins), a supply air blower, filter, a condenser and heat rejection propeller fan. The term "expansion" refers to the method used to introduce the refrigerant into the cooling coil. The liquid refrigerant passes through an expansion device (usually a valve) just before entering the cooling coil (the evaporator). This expansion device reduces the pressure and temperature of the refrigerant to the point where it is colder than the air passing through the coil. Figure 1 shows the schematic of a typical DX air conditioning system.

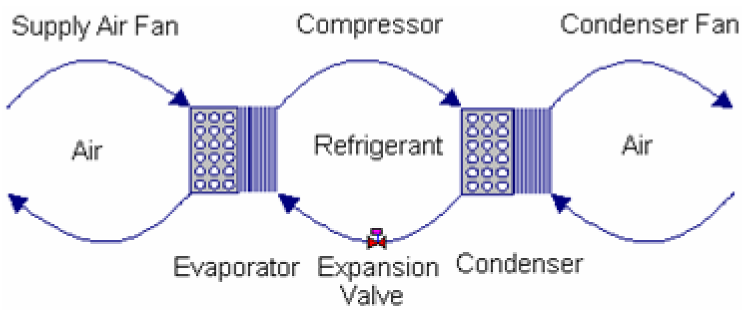

FIGURE - 1
DX SYSTEM

In this schematic, the heat is extracted from the space and expelled to the outdoors (left to right) through 3 loops of heat transfer.

- In the leftmost loop, a supply air fan drives the indoor air across the evaporator, where it transfers its heat to the liquid refrigerant. The resultant cooled air is thrown back to the indoor space. The liquid refrigerant is vaporized in the tubes of the evaporator.
- In the middle loop, a refrigeration compressor drives the vapor refrigerant from evaporator to the condenser and back to the evaporator as a liquid refrigerant. The cycle continues in closed loop copper tubing.
- In the rightmost loop, a condenser air fan drives the ambient air across the condenser, where it transfers heat of refrigerant to the outdoors. The refrigerant is cooled and liquefied after expanding it through an expansion valve located between condenser and the evaporator.

The most common types of DX systems are also referred as “unitary” air conditioning systems. These are factory assembled; self-contained units commonly sold as "off the shelf," package units of varying capacity and types. Each package consists of refrigeration and/or heating units with fans, filters and controls. Depending upon the requirement these are available in the form of room air conditioners, split air conditioners, heat pumps, ductable systems with air cooled or water cooled condensing options.

In the split system, the condensing unit comprising of the condenser, compressor and condenser fan with motor are located outside, while the indoor unit consisting of the evaporator, evaporator fan with motor, expansion valve and air filter is located inside the conditioned room. The indoor and outdoor units are connected by refrigerant piping. Flexibility is the overriding advantage of a split system. Because a split system is connected through a custom designed refrigerant piping system, the engineer has a large variety of possible solutions available to meet architectural and physical requirements particularly for buildings with indoor and/or outdoor space constraints.

DX systems operating in reverse cycle are called “Heat pumps”. Through an addition of a special 4-way reversing valve, heat flow in mechanical refrigeration loop can be reversed so that heat is extracted from outside air and rejected into the building. Heat pumps provide both heating and cooling from the same unit and due to added heat of compression, the efficiency of heat pump in heating mode is **higher** compared to the cooling cycle.

Types

Unitary DX systems come in two types:

1. Room air conditioners
2. Package type conditioners

Room air conditioners provide cooling to rooms rather than the building. These provide cooling only when and where needed and are less expensive to operate. These units are normally mounted either in the window sill or through the wall. For rooms that do not have external windows or walls, a split type room air conditioner can be used.

In the room air conditioners (both window mounted and split type), the cooling capacity is controlled by switching the compressor on-and-off. Sometimes, in addition to the on-and-off, the fan speed can also be regulated to have a modular control of capacity. It is also possible to switch off the refrigeration system completely and run only the blower for air circulation. Both the split type air conditioner and room air conditioners are equally reliable but it is not possible to provide fresh air in split air conditioners. Room air conditioners generally have small damper for letting the fresh air in.

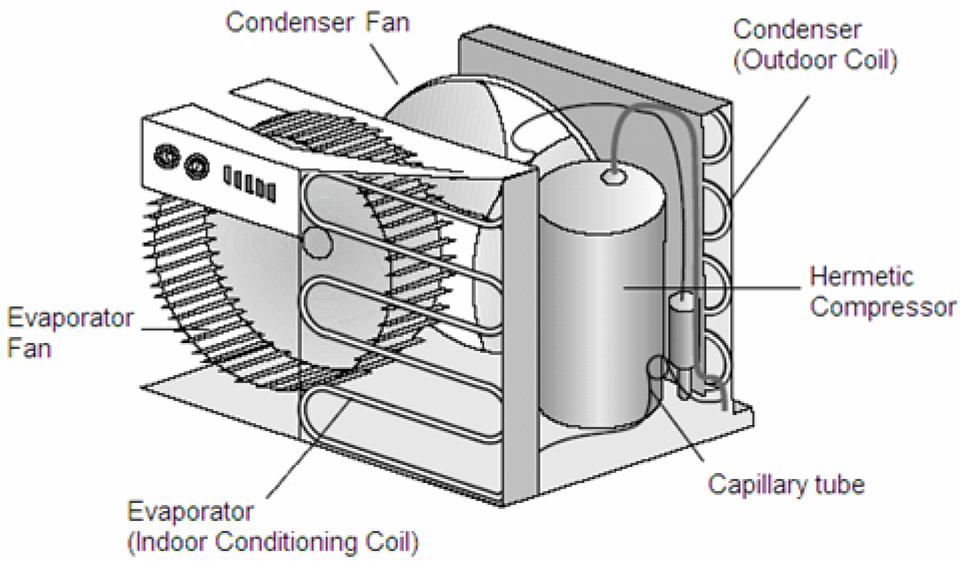

FIGURE - 2
TYPICAL ROOM AIR CONDITIONER

Room air conditioners are generally available in capacities varying from about 0.5 TR to 3 TR*.

Note: **TR*** stands for Ton of Refrigeration and is defined as the ability of the air-conditioning equipment to extract heat. 1TR is equal to heat extraction rate of 12000 Btu/h. Each building is different and the design conditions differ greatly between regions to region.

Packaged air conditioning systems are available in capacities ranging from about 5 TR to up to about 100 TR. This type of system can be used for providing air conditioning in a large room or it can cater to several small rooms with suitable supply and return ducts. It is also possible to house the entire refrigeration in a single package and may also include heating coils along with the evaporator. The condenser used in these systems could be either air cooled or water cooled. Figure -3 shows a packaged air-conditioning water cooled unit designed to operate with dual compressors.

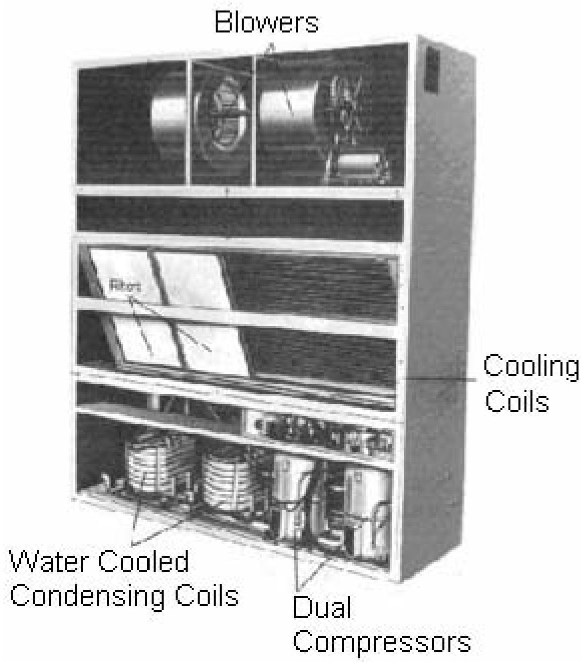

FIGURE - 3
PACKAGED AIR CONDITIONER UNITS

Smaller room air conditioners (i.e., those drawing less than 7.5 amps of electricity) can be plugged into any 15- or 20-amp, 115-volt household circuit that is not shared with any other major appliances. Larger room air conditioners (i.e., those drawing more than 7.5 amps) need their own dedicated 230-volt circuit.

On hotter & humid regions the cooling requirement may be as high as 150 sq-ft/TR and in cooler places it could be as low as 500 sq-ft/TR. For comfort applications, it is reasonable to assume a figure of 250 sq-ft/TR as a rough estimate in absence of heat load calculations.

The overall cost for a packaged system can be as low as $10 per square foot (installed cost, including ductwork and controls). Cost of the unit alone ranges from about $1,500 for a 2-ton unit to around $2,000 for a 5-ton unit. High efficiency package units (when available) cost about 10% more than standard efficiency models.

Ductless or Ducted Units

Small capacity Individual room air conditioning systems are essentially ductless while larger package units use ductwork for air distribution. Ductless products are fundamentally different from ducted systems in that heat is transferred to or from the space directly by circulating refrigerant to evaporators located near or within the conditioned space. In contrast, ducted systems transfer heat from the space to the refrigerant by circulating air in ducted systems.

A standard DX unit is typically rated at 400 CFM (cubic feet per minute) supply air flow rate per ton of refrigeration. Obviously the larger airflow, high tonnage units will need ductwork to cover all spaces and to reduce noise.

Water Cooled or Air Cooled

Refrigeration systems expel heat through condenser by two methods. One method is air cooling where the refrigerant is cooled by air forced over the finned tube coils and the second method is water cooled systems, which reject heat into water that is re-circulated through a cooling tower. The water cooled systems use shell and tube type condenser. Most DX systems use air-cooled finned tube condensers to expel heat. The larger packaged air conditioners may be water cooled or air cooled.

The economics of a water cooled system v/s an air cooled system 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.
- The air cooled condenser have to be generally kept very close to the evaporator units and for smaller sized equipment, the length should be 30 to 40 feet whereas for larger systems it may go up to 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 placed at any distance from the cooling equipment.

Part III of this course addresses this topic in detail.

Efficiency Ratings of DX Equipment

Federal law mandates a minimum efficiency of 10 SEER for both split and packaged equipment of less than 65,000 Btu/h capacities. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) recommend 10 EER for equipment between 65,000 and 135,000 Btuh. ASHRAE standard 90.1 recommends other efficiencies for larger equipment. It is often cost effective to pay for more efficient equipment. For example, upgrading from a 10 SEER to a 12 will reduce cooling costs by about 15 percent. Upgrading from a 10 to a 15 reduces cooling costs by about 30 percent.

Federal Efficiency Standards

Federal size category	**Equipment type**	**System design**	**Effective June 16, 2008**	**Effective January 1, 2010**	**ENERGY STAR minimum criteria**
< 5 tons (< 65 kBtu/h)	Air conditioner	Split system	SEER 13.0	—	SEER 13.0a
		Single-packaged unit	SEER 13.0	—	SEER 13.0a
	Heat pump	Split system	SEER 13.0 & HSPF 7.7	—	SEER 13.0 & HSPF 7.7a
		Single-packaged unit	SEER 13.0 & HSPF 7.7	—	SEER 13.0 & HSPF 7.7a
Small 5 to <11.25 tons [65 to <135 kBtu/h]	Air conditioner	Split system and single-packaged unit	—	EER 11.2	EER 11.0b
	Heat pump	Split system and single-packaged unit	—	EER 11.0 & COP 3.3	EER 10.1 & COP 3.2b
Large 11.25 to 20 tons (135 to < 240 kBtu/h)	Air conditioner	Split system and single-packaged unit	—	EER 11.0	EER 10.80b
	Heat pump	Split system and single-packaged unit	—	EER 10.6 & COP 3.2	EER 9.3 & COP 3.2b
Very large	Air conditioner	Split system and single-	—	EER 10.0	—

20 to 63 tons

(240 to < 760 kBtu/h)		packaged unit			
	Heat pump	Split system and single-packaged unit	—	EER 9.5 & COP 3.2	—

Courtesy: E Source; data from U.S. Department of Energy and EPA

Efficiency Terms

- SEER – The Seasonal Energy Efficiency Ratio is a representation of the cooling season efficiency of a heat pump or air conditioner in cooler climates. It applies to units of less than 65,000 Btu/h capacities. The higher the SEER rating, the more efficient the AC system operates.
- EER – The Energy Efficiency Ratio is a measure of a unit's efficiency at full load conditions and 95 degrees outdoor temperatures. It typically applies to larger units over 65,000 Btu/h capacities.
- HSPF – The Heating Season Performance Factor is a representation of the heating efficiency of a heat pump in cooler climates.
- Btu/h – Btu/h is a rate of heating or cooling expressed in terms of British Thermal Units per Hour.
- Ton – One ton of cooling is the energy required to melt one ton of ice in one hour. One ton = 12,000 Btu/h

Chilled Water Systems:

In chilled water system the air is cooled with chilled water passing through the chilled water cooling coil.

Since the liquid water needs to be at a cold temperature, a "cooling plant" is required. The plant is typically referred to as a chiller. These are usually pre-packaged by the manufacturer with the evaporator and condenser attached, so that only water pipes and controls must be run in the field. The components of a chilled-water system include a chiller, air-handling units with chilled-water coils, chilled-water loop(s) with chilled-water pump(s), a condenser water loop, condenser water pump(s), and cooling tower.

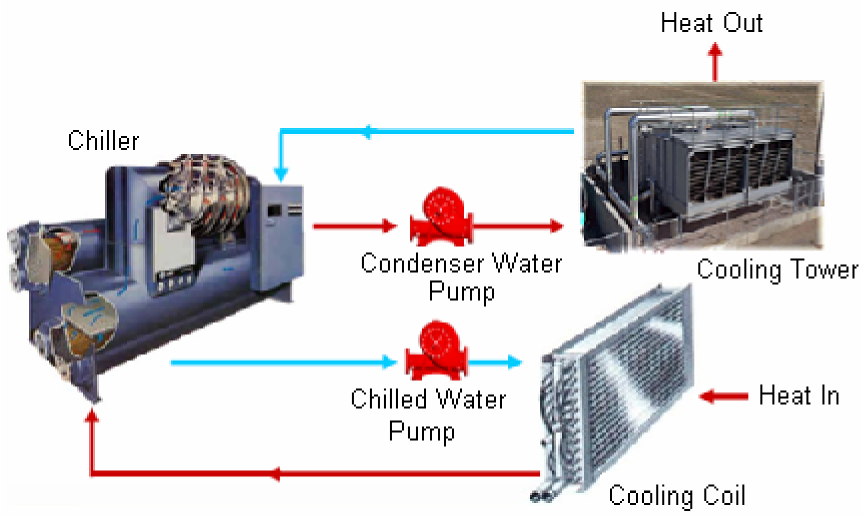

FIGURE - 4
CHILLED WATER SYSTEM

Similar to DX package units, the chilled water systems are categorized as air-cooled or water cooled system. The Figure- 5 shows a conceptual view of chilled water air-conditioning system with air-cooled condenser. The Figure depicts that heat is extracted from the space and expelled to the outdoors (left to right) through 4 loops of heat transfer. The chilled water is produced in the evaporator of the refrigeration cycle and is pumped to a single or multiple air-handling units containing cooling coils. The heat is rejected through an air-cooled condensing unit in the rightmost loop.

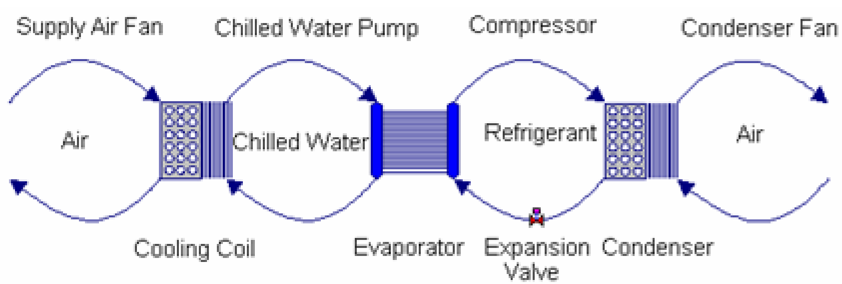

FIGURE - 5
CHILLED WATER SYSTEM WITH AIR COOLED CONDENSER

The Figure - 6 shows a conceptual view of chilled water air-conditioning system with water-cooled condenser and cooling tower.

Here the heat is extracted from the space and expelled to the outdoors (left to right) through 5 loops of heat transfer. The chilled water is produced in the evaporator of the refrigeration cycle and is passed through a single or multiple cooling coils. The heat is rejected through a water-cooled condenser and the condenser water pump sends it to the cooling tower. The cooling tower's fan drives air across an open flow of hot condenser water, transferring the heat to the outdoors.

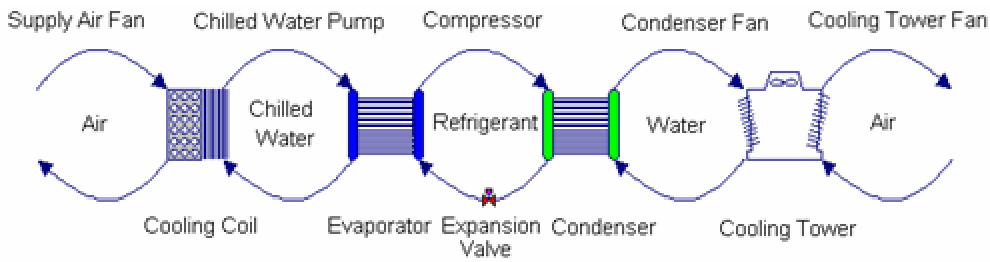

FIGURE - 6

CHILLED WATER SYSTEM WITH WATER COOLED CONDENSER

The main equipment used in the chilled water system is a chiller package that includes

- A refrigeration compressor (reciprocating, scroll, screw or centrifugal type),
- Shell and tube heat exchanger (evaporator) for chilled water production
- Shell and tube heat exchanger (condenser) for heat rejection in water cooled configuration
- Copper tube/Aluminum finned condenser coil and fan (condensing unit) for air cooled configuration
- An expansion valve between condenser and the evaporator

The middle refrigerant loop is connected through a copper piping forming a closed loop. The water circuit on the chilled waterside is connected through an insulated carbon steel pipe and is a closed loop. The condenser water connected through a carbon steel piping is an open loop and requires 2 to 3 % make up water as a result of evaporation, drift and blow down losses of the cooling tower.

Chilled water systems are typically applied to the large and/or distributed areas. Capacity ranges from 20- 2000 TR and are suitable for an area of 3000 square feet and above.

PART II - KEY FACTORS IN SELECTION OF COOLING SYSTEM

Now that we understand the conceptual arrangement of air-conditioning cooling systems, the distinction between the local DX and central chilled water systems is critical from a mechanical, architectural and energy management perspective. Let's analyze the key factors that determine the selection of system.

DX SYSTEM

Check out this statement *"DX system is suitable for a single thermal zone application"*.

What does this mean?

Why it is so?

To answer this, first understand the concept of **thermal zone**. A thermal zone is referred to a space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g. temperature) can be maintained throughout using a single sensor (e.g. thermostat or temperature sensor). Each thermal zone must be 'separately controlled' if conditions conducive to comfort are to be provided by an HVAC system. Few examples below illustrate and clarify the concept of a zone.

- In a building, the perimeter areas with large glazing & exposure are prone to larger solar radiation. Such areas shall experience higher heat load than the indoor core spaces and must be separately controlled.
- In a commercial building, the space containing electronic processing equipment such as photocopiers, fax machines and printers see much larger heat load than the other areas and hence is a different thermal zone.
- A conference room designed for 50 people occupancy shall experience lower temperatures when it is half or quarterly occupied. The design thus shall keep provision for a dedicated temperature controller for this zone.
- In an airport a smoking room shall be categorized as an independent zone for health and safety reasons. A good air-conditioning system should not allow mixing of smoke contaminants with return air of other public lounges.

- A 1000 seat theatre shall be treated an independent zone than the entrance concourse or cafeteria as the dynamics of occupancy are different.
- A hotel lobby area is different from the guest rooms or the restaurant area.
- A hospital testing laboratory, isolation rooms and operation theatre demand different indoor conditions/pressure relationships than the rest of areas and thus shall be treated as a separate zones.
- A control room or processing facilities in industrial set up may require a high degree of cleanliness/positive pressure to prevent ingress of dust/hazardous elements and thus may be treated as separate zone.

In nutshell any area that requires different temperature, humidity and filtration needs or is prone to huge variations in thermal loads shall be categorized as an independent zone. The reason that most modern offices interiors have low partitions is not to do only with aesthetic and spacious looks; it has relevance to keep air-conditioning simple and effective. Zoning may very well be categorized as an architectural responsibility since it requires a good understanding of building function and schedules.

Let's check out why DX systems are only suitable for single thermal zone application. The reasoning is as follows:

1. DX systems do not provide modulating control. The capacity control in DX system with fully hermetic sealed compressor is generally accomplished by cycling the compressor ON and OFF in response to the signals from a thermostat. What this means is that the DX system will only have one point of control – typically a thermostat. Thus two rooms with thermostat controllers set at say 22°F and 28°F shall conflict with each other or in other words the two rooms cannot achieve the set conditions unless the rooms are served with independent units. Semi-hermetic compressors offer the benefit of being able to unload pairs of cylinders within a single compressor. For instance, a compressor with six cylinders can be staged to operate at 100%, 67% and 33% capacity by operating on six, four, or two cylinders respectively. These provide only limited step modulation.

   The issue of system control leads to the concept of HVAC zoning just like architectural zoning. Active HVAC system may be designed to condition a single space or a portion of a space from a location within or directly adjacent to the space.

2. DX systems cannot be networked conveniently. The refrigerant piping plays a key role in connection of various components in terms of size, length and pressure drop. Split units installation is restricted by distance criteria between the condensing unit and the evaporator, which is usually 30 to 40 feet for smaller units and around 100 to 120 feet for larger units. For large buildings consisting of multi-zones, DX system may be viewed as collection of multiple independent units placed at different locations in a distributed network with each unit working in isolation. Each DX system is thus local self-contained unit consisting of its own compressor/s, evaporator coil, fan, condensing unit and filtration unit. Depending upon the capacities required and areas served the DX system could be room air conditioners, split air-conditioners or package air conditioners. All these serve a single thermal zone and have its major components located in one of the following ways:

    - Within the zone
    - On the boundary between the zone and exterior environment
    - Or directly adjacent to the zone

Newer DX Configurations/Options

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

<u>Variable Air Volume (VAV) Units for Ducted Package Systems</u>

Variable air volume (VAV) components can be fitted on the air distribution ductwork thus affording good control of conditions within the respective thermal zone. Variable air volume system (VAV) delivers a constant temperature of air and responds to changing thermal loads by varying the quantity of supply air.

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 $ 300- for a 400 cfm size diffuser.

<u>Variable Refrigerant Flow (VRF) System for Multiple Evaporators</u>

The term variable refrigerant flow (VRF) refers to the ability of the system to control the amount of refrigerant flowing to the multiple evaporators, enabling the use of many evaporators of differing capacities and configurations connected to single condensing unit.

The arrangement provides an individualized comfort control, and simultaneous heating and cooling in different zones. This refrigerant flow control lies at the heart of VRF systems and is the major technical challenge as well as the source of many of the system's advantages.

Many zones are possible, each with individual setpoint control. Because VRF systems use variable speed compressors with wide capacity modulation capabilities, they can maintain precise temperature control, generally within ±1°F (±0.6°C), according to manufacturers' literature.

VRF system being the split installation is restricted by distance criteria between the condensing unit and the evaporator. Although few manufacturers' literature states the refrigerant lines can be as long as 500 feet, but when you read the fine print, after the first 'Tee' from the condensing unit, you are limited to 135 feet to the furthest unit. Other than the restricted distance criteria between evaporator and condensing unit, there are some legitimate concerns that need to be addressed.

- VRF systems are complete, proprietary systems, from the controls right up to the condensing units, refrigerant controllers, and all the system components other than the refrigerant piping. That means users do not have the flexibility to use "anybody's" building control and automation system to run these systems. You'll need a BacNet or Lonworks black box to connect from your building DDC system to the VRF system, and you can only monitor what it's doing, you can't control it.
- As the system has a larger spread, the refrigerant pipes traverse long lengths - hence their pressure testing and protection becomes critical. Long refrigerant piping loops also raise concerns about oil return;
- Long refrigerant lines also raise the potential of refrigerant leaks, which can be a safety hazard. The refrigerant leak especially if the system serves small rooms can cause oxygen depletion. So you need to limit the system size within reasonable limits based on smallest room area served. For e.g. if the room area is 100 sq-ft, you would need to limit the refrigerant qty under less than about 30 lbs. Contractors are concerned about long refrigerant piping runs for multiple evaporators. They believe

that compliance with ANSI/ASHRAE Standard 15-2001, Safety Standard for Refrigeration Systems, is difficult;

- Currently, no approved ARI standard exists for a performance rating of VRF systems. Consequently, manufacturers need to apply for waivers from the Department of Energy to market their products in the U.S. Although these waivers have been granted, new applications need to be submitted for new product groups;
- VRF systems are expensive and complex. The complicity involved in VRF/VRV is continuous and have to be dependent on the Vendor who has supplied for life of equipment.

<u>Multiple Compressors</u>

A unit with two equally sized fully hermetic compressors may operate at 100% and 50% capacity by starting or stopping one of the two compressors. Unequally sized compressors provide greater staging flexibility; for instance, a 30-ton unit with two compressors rated at 10 tons and 20 tons will have capacity stages at 33%, 67% and 100%.

Factors favoring DX system:

- One of the most common reasons for selecting a DX system, especially in a smaller buildings is the lower installed cost than a chilled-water system because it requires less field labor and has fewer materials to install;
- DX systems tend to be distributed for larger buildings that increase reliability; a building conditioned using DX system may have a dozen or hundred of individual and independent units located throughout the building. Failure of one or two of the units may not impact the entire building. On a smaller scale this may be viewed as a disadvantage unless standby is provided;
- If the tenants are paying the utility bills, multiple packaged DX units may make it easier to track energy use, as only the specific unit serving that tenant would be used to meet the individual cooling requirements;
- DX systems are not complicated by interconnections with other units. Maintenance of local systems tends to be simple and available through numerous service providers;

- In buildings where a large number of spaces may be unoccupied at any given time, such as dormitory, small hotels etc. the local DX systems may be totally shut off in the unused spaces thus providing potential energy savings;
- For small areas within full scale offices like 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;
- DX systems can be installed quickly and their operation is relatively simple. Offer short delivery schedules and generally available as factory standard off the shelf unit. Easy to install and replace. Compact and require a smaller footprint than alternatives;
- As a self contained system, a DX system may provide totally individualized control options, for instance, if one room needs heating while an adjacent one needs cooling, two local systems can respond without conflict;
- DX unitary systems are ideal for retrofitting applications. These may be used to supplement areas of inadequate service by a building's existing central system;
- Air cooled condensers can be located on the roof of the building or even within the perimeter wall of the building. Cooling unit is available in wide variation of floor, wall as well the ceiling suspended units;

Limitations of DX system:

- DX systems cannot benefit from economies of scale. Capital costs and the operating costs generally tend to be higher for larger setups requiring 100TR or more. The building designer must thoroughly evaluate all pertinent installation, operating, and maintenance costs to make an informed decision;
- DX systems cannot be easily connected together to permit centralized monitoring or energy management operations. These can be centrally controlled with respect to on-off functions only;
- DX units have capacity control limitations; compressor unloading systems are generally step devices, which limit capacity modulation. At low load conditions, the compressors will cycle and unconditioned air will pass through the system during the

off cycle, which may cause temperature swings (i.e. hot and cold spots) in the conditioned space;

- The coefficient of performance (COP) of a DX system is low. Unitary systems consume more power (kW per ton) compared to central systems of same capacity;
- Lack of interconnection between units also means that loads cannot be shared on a building wide basis. Central HVAC systems deliver improved efficiency and lower first cost by sharing load capacity across an entire building;
- 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 (unless variable air volume (VAV) units are considered);
- Multiple DX systems using window or small capacity split units may spoil the exterior elevations and aesthetics of the building;
- For distributed DX systems, although the maintenance may be relatively simple, such maintenance may have to occur directly in occupied building spaces;
- DX systems may not be suitable for the applications requiring high air delivery rates and the areas requiring significant positive pressurization (unless the DX systems are engineered). The standard unitary systems provide 400 cfm of air delivery capacity per ton of refrigeration;
- DX systems are not suitable for areas requiring high degree of cleanliness unless the systems are custom built. The standard units generally provide fan static pressure of 2 to 3 inch water gauge, which may not be sufficient to cope up the resistance of high efficiency filtration;
- DX systems installation many a times require plumbing arrangements with in the conditioned area if the cooling unit is placed indoors. The design should take into account the condensate removal required from the conditioned space and the possibility of leakage;
- DX window or small split-air conditioners are free air discharge units and are non-ducted. Multiple units or package unit shall be needed to optimize air distribution where the span of building (length or width) exceeds 12 feet;

- Smaller split units with cooling (evaporator) unit located indoors in conditioned space are 100% re-circulation units. They do not provide ventilation, so a separate ventilation system is necessary;
- Split DX systems are constrained by distance limitation of approximately 30 to 100 feet between condensing unit and evaporator. Chilled water systems are not constrained by any separation distance criteria between chiller and the cooling coil;
- Special requirements of surface coating may not be available on the condensing equipment placed outdoors in harsh corrosive/saline environment. The condensing unit will therefore have a shorter life span;
- Multiple DX systems for large area applications shall require larger footprint of mechanical room or quite a number of mechanical rooms.

Applications:

- The DX systems are suitable for small or medium sized buildings free of multiple thermal zones and demanding 100 TR or less of air-conditioning. For big areas such as Wal-Mart store requiring say 200 TR of refrigeration, DX system may be viewed as 4 units of 50 TR each subject to availability of space and aesthetics;
- DX systems are more effective for the services requiring low temperature and low humidity conditions. The application includes the grocery stores, fruit & vegetable stores, meat processing units, instrument rooms, laboratories, bio-medical labs, critical manufacturing and process facilities;
- DX systems can be applied along with central chilled water system for areas requiring 24hrs operation such as server rooms, data centers etc. DX systems can be also be applied for augmenting the HVAC needs in the existing central HVAC systems necessitated due to expansion or addition of more equipment;

KEY FACTORS IN SELECTION OF CHILLED WATER SYSTEMS

Chilled-water system predominate the large commercial buildings where the cooling demand exceeds 200 tons of refrigeration. The chilled water system can truly be referred as central air conditioning system because these can be easily networked to have multiple air handling units distributed throughout the large distributed buildings and the main chiller package placed at one central location.

Factors favoring Central Chilled Water Systems:

- Water has a far greater heat capacity than air. The following is a comparison of these two media for carrying heat energy at 68°F:

	Air	**Water**
Specific heat, Btu/lb • °F	0.243	1.0
Density, at 68°F, lb/ft^3	0.075	62.4
Heat capacity of fluid at 68°F, Btu/ft^3 • °F	0.018	62.4

  The table shows, the heat capacity per cubic foot of water is 3466 times greater than that of air. Therefore transporting heating and cooling energy from a central plant to remote air-handling units in fan rooms is far more efficient using water than conditioned air in a large air conditioning project;

- Capacity control in chilled water systems is usually achieved by modulating the chilled water flow through multiple cooling coils served from a single chiller without compromising control on any individual unit. Chilled water flow rate can be closely controlled allowing closer temperature tolerances in space under almost any load condition. In contrast, direct expansion equipment generally has a 'fixed' off coil temperature during the cooling mode and it provides either an on/off control or step control;
- Grouping and isolating key operating components in mechanical room allows maintenance to occur with limited disruption to building functions;
- Since mechanical room is isolated from the master building served, the noise is reduced and aesthetic impact is minimal;
- Multiple units applied with chilled water system offer greater redundancy and flexibility as either of the compressors (main & standby) can act as standby to any of the air-handling units (main & standby). In the DX system one compressor is associated with one air-handling unit cooling coil, hence the flexibility & redundancy of operation is limited;

- Chilled water systems are the engineered systems that are generally supplied as the custom built units. These can be fabricated to suit the designer application and the air delivery rate can be sized irrespective of the refrigeration capacity. In contrast the DX systems usually provide fixed 400 CFM per ton of refrigeration;
- Central systems provide opportunity for economies of scale and results in low capital and operating costs over 100TR;
- A central chilled water system using high efficiency water cooled chillers provide greater efficiency than individual units, but efficiency and stability of operation of central systems can be compromised when only a small proportion of space is using air conditioning.
- Central systems are amenable to centralized energy management systems that if properly managed can reduce building energy consumption besides providing effective indoor temperature and humidity control;
- From climate control perspective, the active smoke control and building pressurization is best accompanied by the central HVAC system;
- Another benefit of a chilled-water applied system is refrigerant containment. Having the refrigeration equipment installed in a central location minimizes the potential for refrigerant leaks, simplifies refrigerant handling practices, and typically makes it easier to contain a leak if one does occur.

Concerns about Central Chilled Water Systems:

- As a non-distributed system, failure of any key equipment component (such as pump or chiller) may affect an entire building. Standby equipment needs to be perceived during design;
- As system size and sophistication increase, maintenance may become more difficult and may be available from fewer providers and specialists may be needed;
- The need to transfer conditioned air or water imposes space and volume demand on a building. Larger duct sizes, for example may require an increase in floor-to-floor height and consequent, building cost;

- Though COP of large-scale central plant is high, the applications requiring part load operations may consume high energy. System configuration in terms of multiple chiller units needs to be perceived for overall economy during conceptual stages;
- Chilled water systems because of limitation of water freezing at 32°F, and limitation of chiller to generate say up to 36 or 38°F, cannot guarantee chilling temperature and extreme low humidity for critical service applications such as grocery stores, meat processing or chilling applications. These are good for comfort applications.

The central system shall be considered for the applications, where multiple zones are to be cooled, or where multiple AHU's are required due to large, diverse, and distributed buildings. The applications include multistoried buildings, commercial office buildings, shopping malls, large departmental stores, distributed facilities such as school campus, medical facilities, industrial facilities, entertainment parks etc. etc.

PART III - FACTORS DETERMINING THE HEAT REJECTION SYSTEM

There are two prominent types of heat rejection equipment; 1) Air cooled and 2) water cooled. Selection of heat rejection equipment has traditionally been a choice between higher energy consumption of an air cooled solution v/s high water consumption of a water cooled solution. There is a fine line that needs to be examined on a case by case basis. The salient parameters are:

1. **The Capacity of Plant:** The air-cooled machines are easy to install and takes lower space compared to water-cooled machines on lower sizes. The space requirements for air-cooled machines however increase significantly for nominal capacities above 200 TR. If the plant is larger than 200 TR and is not packaged, it should be water cooled as:

   - It will provide the best energy result;
   - The capital cost will be appropriate to the size of plant;
   - Chemical refrigerant will be minimized.

   Multiple air cooled DX systems are possible after analyzing all pros and cons.

2. **Availability of Water:** The places where water is scarce, every drop of water must be carefully used in an economically feasible manner. The water demand in some regions is primarily met by groundwater abstraction, desalination plants and recycled wastewater. All water treatment is costly. As an estimate desalinated water production costs range from 2.5 US$/ 1000 gallons to 4.4 USD/ 1000 gallons with an average cost of 3.0 USD/ 1000 gallons. Water-cooled condensers designed for 10°F "range" typically requires, 3 GPM of cooling water per ton of refrigeration. Nearly 2% of cooling water is lost in evaporation, drift and blow down through the cooling tower. Therefore, for a 100 TR capacity plant, the water loss works out to be 6 GPM or 8640 gallons per day. This translates to a processing cost of nearly US $9500 @ US $ 3.0 per thousand gallons. Of course the costs shall be significantly higher with higher HVAC capacities.

   Air cooled condensing is preferred where water is scarce and/or involve very high treatment costs.

3. **Quality of Water:** The quality of water does matter. Ozone treatment or automatic biocide dosage shall be required to limit the growth of Legionella bacteria associated with water cooled options.

4. **First Costs:** Air-cooled condensers have a lower initial cost due to lower number of components. Unlike water cooled options, air cooled condensers do not require pumps, auxiliaries and associated piping. With lesser components the associated civil costs also tend to be low.

5. **Operating Costs:** The kW/ton energy consumption of air-cooled systems is higher compared to water-cooled machines and for unit capacities exceeding 200TR, water cooled machines consume less energy. Air cooled condenser requires some potential temperature difference in order to reject heat, so the refrigeration system must operate at a higher head pressure and temperature to produce this temperature difference. Air cooled condensers normally requires between 125°F to 130°F condensing temperature to reject heat to a 100°F ambient, while a water cooled condenser can operate at 105°F condensing temperature and reject its heat to a 95°F water stream. Because air is a poor conductor of heat, water cooled condensers can operate with a much lower approach temperature. However, the operation cost of an air-cooled condenser system on small capacities shall be more economical because of the lower number of power driven auxiliaries and the zero water treatment costs.

6. **Maintenance:** Water-cooled systems will always cost more to maintain due to the constant water treatment requirements and the need for regular tube cleaning. Water-cooled chillers will generally last longer, however, particularly in harsh environments such as near oceans where salt in the air can significantly shorten the life of air-cooled condensers.

7. **Potential for Heat Recovery:** Heat recovery is easier to obtain and control when using water cooled condenser because water has a far greater heat capacity than air. Heated water from the refrigeration cycle can be diverted to heat other processes and even provide space heating during winter months.

8. **Flexibility of Control:** Water-cooled machines provide better control of indoor conditions at extreme ambient conditions. The performance of an air-cooled condenser machine reduces significantly at higher ambient temperatures and requires considerable

over sizing to overcome the extreme high ambient temperatures. The thermal efficiency of air-cooled condensers is lower than that of cooling towers.

9. **Other Governing Criteria:** Air-cooled condensers are restricted by distance separation and the installation height differential between the evaporator and the condensers. Typically the condensers should not be more than ~120 ft above or below and not more than ~ 240 feet away from the chilling machine.

Provided all above factors are taken into consideration, the following rules apply:

- For cooling loads below 100–125 tons, the initial capital and recurring maintenance costs for a water-cooled system are rarely justified and the **chiller(s) shall be air-cooled**.

- Above 200 tons capacity systems and with the use of rotary compressor chillers, the water-cooled condensing option becomes justifiable. Note that the **centrifugal chillers** are always water cooled due to lower compression ratio.

- Between 100 and 200 tons peak cooling load, it becomes a matter of the owner's ability to deal with the maintenance requirements of a cooling tower system and the capital funds available.

We will discuss the various heat rejection methods further in following section:

METHODS OF HEAT REJECTION

The five prominent ways of heat rejection are:

1. Air cooled condensing units
2. Closed circuit coolers
3. Evaporative condensers
4. Cooling Towers
5. Adiabatic condensers

Background

It is important to understand "what heat of rejection is" before discussing the selection of appropriate method, equipment or technology.

Heat of rejection is the energy removed from a refrigerant in the condensing process. Hot gaseous refrigerant enters the condenser where it loses its latent heat of evaporation to become hot liquid refrigerant. That process occurs regardless of the method adopted to absorb the heat rejected.

In typical terms the heat of rejection is some 18% to 28% **greater** than the cooling effect in the evaporator. This is because the heat of compression is added into the system. The actual percentage that occurs depends upon a number of factors including the suction temperature and the discharge temperature. Low suction temperature and/or high discharge temperature increases the percentage. As an example: Standard selection for reciprocating compressor operating on HCFC-22 is usually 40°F saturated suction and 105°F condensing temperature. The heat of compression at this condition is typically 18.6%. If the same compressor operates at 40°F saturated suction and 120°F condensing temperature, the heat of compression shall be 23.6% and if it operates at 30°F saturated suction and 105°F condensing temperature, the heat of compression shall be 21.8%. The selection of refrigerant has little impact upon the percentage result.

It should be remembered that most DX systems employ hermetic /semi-hermetic compressors where the compressor motor is contained within the compressor housing and that motor cooling is achieved by passing the cool refrigerant gas returning from the evaporator over the motor windings. As the motor is cooled, the heat energy is passed to the refrigerant vapor, which must be rejected at the condenser to atmosphere. Condensers are therefore slightly larger for hermetic / semi-hermetic systems than for open-drive systems where the motor is itself air-cooled.

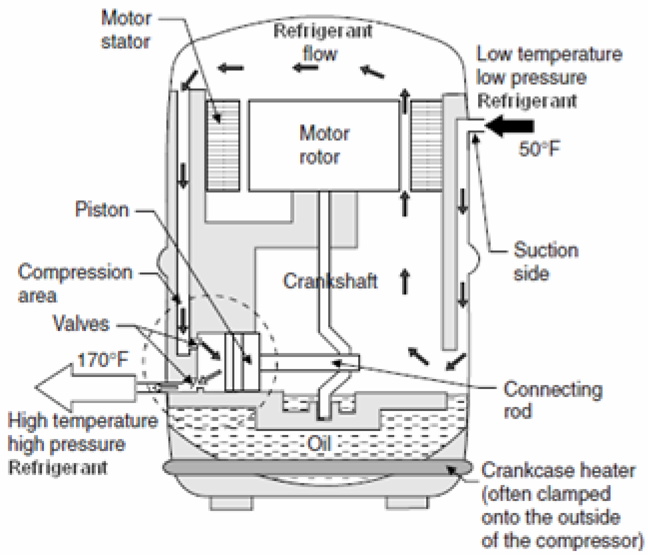

FIGURE - 7
CROSS SECTION OF HERMETIC COMPRESSOR

Further factors in the control of a refrigeration system are superheat and sub-cooling.

Superheat is the temperature difference between the boiling point of the refrigerant in the evaporator and the actual temperature of the refrigerant gas after the evaporator. It is the "extra" heat added to the refrigerant vapor beyond what is required to vaporize all of the liquid. Superheat therefore is not latent, but sensible heat that is measured in degrees. Superheat from the evaporation phase has a corresponding increase in the total heat of rejection at the condenser and results in the compressor operating at higher temperature. While some amount of superheat is required to protect the refrigeration system and prevent liquid entering the compressor, too much superheat can contribute to oil breakdown and increased system downtime. Super heat should be in the order of 5.5°K.

Sub-cooling is the process of cooling condensed gas beyond what is required for the condensation process. Sub-cooling can have a dramatic effect in the capacity of a refrigeration system by increasing the capacity of the refrigerant to absorb heat during the evaporation phase for the same compressor KW input. Studies indicate that 1°K of sub-cooling can increase the refrigeration effect by up to 1%. Sub-cooling is best accomplished in a separate sub-cooler or a special sub-cooling section of a condenser because tube surface must be submerged in liquid refrigerant for sub-cooling to occur. In an air cooled, adiabatic and evaporative condenser, a secondary coil is used to achieve the sub-cooling. Optimal sub-cooling for an air conditioning plant is 8.3°K.

AIR COOLED CONDENSING UNITS

As the name suggests, an air-cooled condensing unit uses outside air to remove heat from the refrigerant. It consists of a finned coil fabricated of aluminum fins hydraulically or mechanically bonded over copper tubes and a fan(s) assembly. The fan forces air across the coil containing the hot refrigerant and discharges that heat into the ambient air.

Compared to water, air is a poor conductor of heat and therefore air-cooled units are larger and less efficient. The performance of the air cooled condenser is dependent on the airflow rate and the air's dry bulb temperature. As the ambient air temperature increases, the condensing temperature increases and net cooling capacity decreases by about 2% for each 5°F increase in condensing temperature. The typical condensing temperature for an air-cooled chiller is 120°F as opposed to a 105°F in a comparable water condensed chiller. Air-cooled condensers typically operate at air flow rates range from 600 to 1200 cfm/ton with a 10–30°F approach, which is defined as the temperature difference between the refrigerant condensing temperature and the ambient dry bulb temperature.

Air-cooled condensers also operate at higher compressor ratios – which mean less cooling per watt energy consumption.

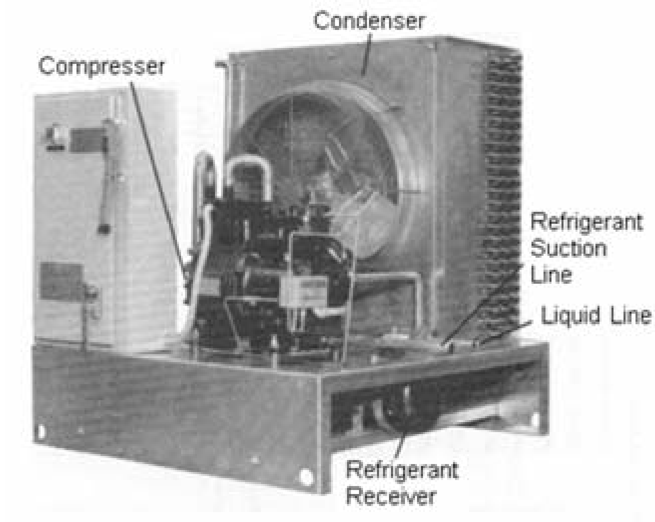

FIGURE - 8
AIR COOLED CONDENSING UNIT

Limitations

- The largest air cooled condenser available in a packaged range is 250 TR. This equates to the cooling effects to roughly 200 TR (assuming 25% heat of compression). The foot print for a horizontal unit of this size shall be roughly 7.5m x 2.4m with an access need of 1.2M all around;
- Propeller fan(s) used in the condensing unit can be a relatively loud noise source that may require special consideration depending on the application. The manufacturer’s technical data will normally quote the noise level generated by each product. It must be remembered that where two or more air cooled condensers are sited in close proximity that the cumulative sound levels will be greater than that of a single unit. The largest unit available has ten fans and the noise level can exceed 88dBA and may require noise abatement treatment. Air cooling also requires considerable fan horsepower;
- Ambient conditions are a limitation; because of the high dry bulb temperature and low heat transfer coefficients for air cooling, the condenser is large and the condenser temperatures are increased. However, an air cooled condenser can operate at extremely high ambient condition provided the temperature rise across the coil is low and in extreme conditions a lower pressure refrigerant such as HFC134a is used;

- Fin material for the coils is susceptible to corrosion so that is also a factor in their selection. The most cost effective fin material is aluminum. Copper will give marginally better performance but at significantly greater cost. Stainless steel fin has a higher cost again and, due to relatively poor thermal conductivity, performance can reduce to as little as 50% of a similar unit constructed from copper tubes in aluminum fins. Salt spray or traffic pollution can corrode the fins within five years. Protective coating can be applied to the fins but it's not always successful.

Benefits

Air-cooled split systems are ideal for any location where the availability of water is limited, or the use of water is restricted for conservation or health reasons. Even if water is not restricted, any facility that benefits from avoiding the capital, maintenance, and operating costs of water-cooled systems is a suitable application.

Warning

The refrigerant condensing temperature is the saturated temperature corresponding to the pressure of the refrigerant entering the condenser and is therefore adversely affected by the pressure drop within the discharge line leading from the compressor. If a condenser is designed to operate at a 10K TD, a pressure drop in the discharge line equivalent to 1K drop in refrigerant saturation temperature will reduce the capacity of the condenser by 10%. An element of care is thus necessary to design refrigerant piping, especially for long piping runs. Improperly designed piping can cause the system to lose capacity. At worst, improperly designed piping can cause compressor failure.

Specific design issues include:

- A separate sub-cooling coil should be fitted to every condenser to ensure the liquid flow from the condenser to the hots liquid side is stable;
- There must be a liquid receiver with every condenser. If there is no receiver the refrigerant charge is considered critical meaning the amount of refrigerant in the system must be exact if it is work correctly;
- The pipe line carrying refrigerant from the condenser to the receiver is not a liquid line. It is a condensate line that must be larger than a liquid line so the liquid can

drain out of the condenser into the receiver. Consequently the receiver must be below the condenser by a considerable distance;

- A liquid line leaves the bottom of the receiver and runs to the sub-cooling coil and then to the expansion device;
- Flash gas will form in the top of the receiver so it must vent though a small valved line to the top of the discharge (hot gas) line before it enters the condenser.

CLOSED CIRCUIT FLUID COOLERS

Closed circuit fluid coolers are the hybrids that pass the working fluid through a tube bundle, upon which clean water is sprayed and a fan-induced draft applied. The resulting heat transfer performance is much closer to that of a wet cooling tower, with the advantage provided by a dry cooler of protecting the working fluid from environmental exposure.

Heat rejection from the refrigerant is to condenser water (CW) passed through the condenser vessel or other form of heat exchanger. The CW is circulated in a closed circuit, so not open to atmosphere at any stage, and passed through a coil bank of tubes in the closed circuit cooler. Water from the basin of the cooler is sprayed over the coil bank to extract heat from the CW in the coils and ambient air is drawn over the coils to evaporative cool the spray water in what is almost an adiabatic process. The heat transfer process from CW to the spray water is purely sensible as the result is a reduction of say 5.5°K in the CW temperature. The increase in the spay water temperature is transferred to the cooling air in an evaporative process.

A closed circuit cooler does not impact upon sub-cooling or superheat of the refrigeration process. Sub-cooling happens in the condenser vessel in whatever form it may be.

Closed circuit coolers are feasible but they are generally expensive and have a life expectancy less than a cooling tower.

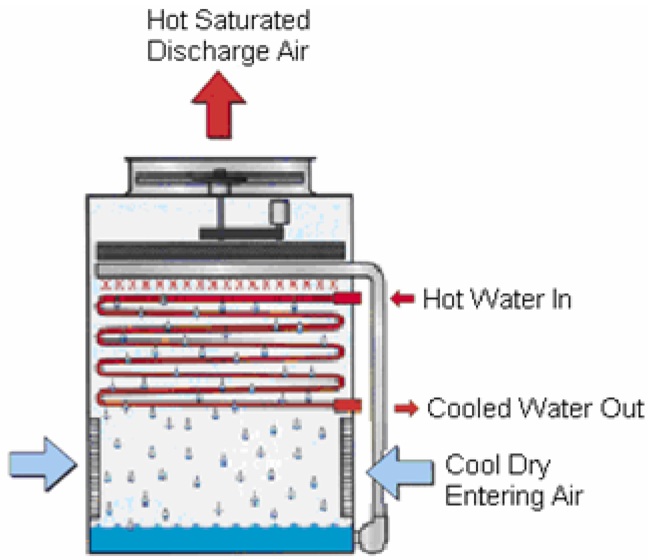

FIGURE - 9
CLOSED CIRCUIT COOLER

Limitations

- Cost is usually high;
- Closed circuit coolers are usually very heavy due to amount of metal in their construction, and the footprint can be relatively small. Slab or frame strength for the support structure must be checked;
- They are difficult to clean. By the very nature of the evaporative effect, scale will build up on the outside of the coil bank making it almost impossible to clean;
- Ambient wet bulb is a selection limitation as the heat transfer depends upon the approach between spray water temperature and the ambient wet bulb temperature. The higher the approach, the higher will be the cooling effect;
- While approach is a key factor, selection criteria is ambient wet bulb and CW flow.

Benefits

The prime benefit is that a water cooled performance is achieved in respect of the refrigeration effect with a closed water circuit. Once treated, the water should remain inert with no degradation of condenser performance due to scaling.

EVAPORATIVE CONDENSERS

An evaporative condenser is similar to closed circuit cooler but refrigerant replaces the water in the tubes. Refrigerant passes through a copper tube bundle in the evaporative cell. Water cascades over its outer surface and airflow counter to the flow of water causes some of the water to evaporate. This results in the efficient cooling of the refrigerant.

There is a sump in the bottom of the condenser to store water and a pump draws the water to spray over the coils. In the winter, the pump is de-energized and only the air flowing across the coils is sufficient to cool the refrigerant. The chiller thus becomes air-cooled.

The design of system pipe work around an evaporative condenser should not be undertaken unless the designer has a clear understanding of refrigeration. The same rules apply to an evaporative condenser as to an air cooled condenser.

- A receiver is essential regardless of what some contractors will try to impose upon the design;
- A separate sub-cooling coil is also essential for the proper control of liquid flow;
- The condensate line out of the condenser coil must drain freely to the top of the receiver of the condenser simply will not work and there will be high head pressure problems;
- Flash gas must be vented off the top of the receiver to hot gas line before it enters the condenser, and under no circumstances should two condensers be used in a common circuit unless the design and installation is carried out by experienced people. The balance of liquid flow out of condensers must be precise or one of the condensers will not work.

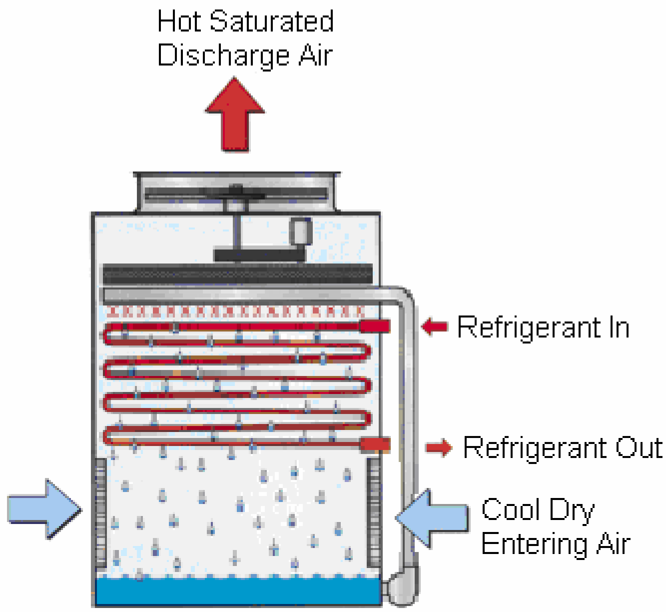

FIGURE - 10
EVAPORATIVE CONDENSER

Limitations

- Limitations for the use of an evaporative condenser are the same as for an air cooled condenser except the foot print. The physical size of an evaporative condenser is less than needed for an air cooled solution;
- The greatest limitation is capacity. As a rule of thumb a field piped refrigeration system will have a gas charge of up to 4.5lbs/TR and that means a 300TR plant will 1350 lbs of chemical refrigerant in circulation. The potential for a leak is high, and the impact of the leak is financially significant but an ecological disaster. It is suggested that 200TR be the maximum size of plant to use an evaporative condenser;
- Ambient wet bulb is critical and it again relates to approach. Higher wet bulb ambient conditions produce less heat rejection capacity. It is suggested that wet bulb selection criteria be 0.5°K above the normal design ambient.

COOLING TOWER

Air conditioning systems captures the heat energy from within the environment and transfers it to the condenser water system. In turn, the condenser water system rejects heat energy through cooling tower(s) to the atmosphere, returning cool water to the chiller for the cycle to be repeated. A standard water cooled condenser is rated at 85° ambient outdoor air temperature but performance data is usually provided for 65° and 75° ambient outside air temperature.

Wet cooling towers or simply cooling towers operate on the principle of evaporation. Warm water, that has removed heat from an air conditioning condenser, enters the top of the tower. As the water falls through the tower fresh air is forced through it. This fresh air cools the water. The cooled water then falls to a storage basin before being recirculated through the system again. When the water is recirculating through the system it gathers heat from an air conditioner before returning to the top of the tower.

Water-cooled chillers are normally more energy efficient than air-cooled chillers due to heat rejection to tower water at near wet-bulb temperatures. Air-cooled chillers must reject heat to the dry-bulb temperature, and thus have lower average reverse-Carnot cycle effectiveness. Large office buildings, hospitals, schools typically use one or more cooling towers as part of their air conditioning systems.

HVAC use of a cooling tower pairs the cooling tower with a water-cooled chiller or water-cooled condenser. A ton of air-conditioning is the rejection of 12,000 Btu/hour. The equivalent ton on the cooling tower side actually rejects about 15,000 Btu/hour due to the heat-equivalent of the energy needed to drive the chiller's compressor. This equivalent ton is defined as the heat rejection in cooling 3 U.S. gallons/minute of water 10°F, which amounts to 15,000 Btu/hour, or a chiller coefficient-of-performance (COP) of 4.0. This COP is equivalent to an energy efficiency ratio (EER) of 13.65.

The key factors to be considered in sizing a cooling tower are the wet bulb temperature, approach and heat load. The heat load in determined by the process duty, the local climate determines the wet bulb temperature and the remaining factor, approach determines the minimum temperature that can be achieved in the evaporative cooling process. Striving for a low approach temperature is desirable, as it lowers the condenser temperature. A small approach means a larger cooling tower.

The difference in temperature between the water entering and leaving the cooling tower is known as the cooling range. The range is determined by the cooling tower heat load imposed by process and water flow rate and NOT by the size or capability of the cooling tower. Increasing the range reduces the water flow rate and the pumping power.

Mechanical draught towers are classified as either “forced draught”, where the fan(s) is arranged to blow air through the tower and is located on the entering air side of the tower OR “induced draught” where the fan(s) is located on the leaving air side of the tower and the fill is under negative pressure. Forced draught towers are characterized by high air entrance velocities and low exit velocities, which can make them susceptible to recirculation, giving instability in performance.

Induced draught towers have an air discharge velocity of from 3 - 4 times higher than their air entrance velocity, and the location of the fan in the warm air exit stream provides excellent protection against the formulation of ice on the mechanical components. Induced draught towers can be used on installations as small as 20 gallons per minute (GPM) and as 2500 GPM.

Tower types are also classified by airflow. In counterflow towers, the water and air flow in opposite directions, i.e. the water flows vertically downward and the air flows vertically upward. In crossflow towers, the two flow streams are arranged at 90° to each other, i.e., the water flows vertically downward through the fill, while the air flows horizontally through it.

Each type of tower has distinctly different fan power and pump head energy consuming characteristics. Both are draw-thru arrangement where a fan induces hot moist air out the discharge. Each has advantages and limitations.

Crossflow towers are the better selection when it is desirable to minimize tower fan energy consumption, minimize pump size and pumping energy, and provide ease of maintenance.

The counterflow tower is the better selection with the available space (footprint) is limited and/or where icing during winter operation is a concern. Counterflow towers are typically expensive to build and have higher capital cost compared to crossflow tower.

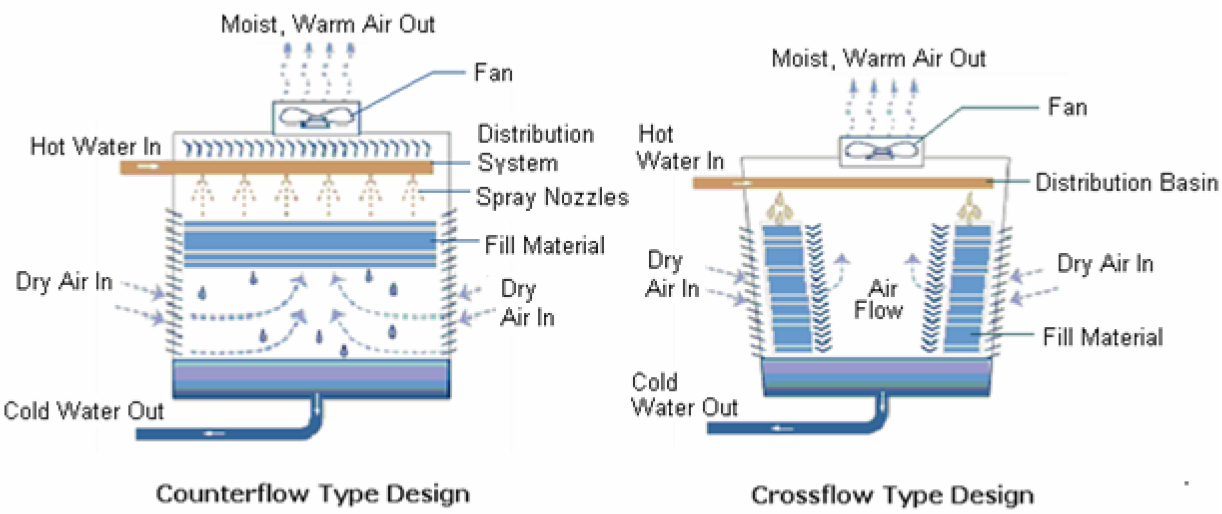

FIGURE - 11
TYPES OF COOLING TOWER

Benefits

- Cooling tower systems when compared to air cooled condensers provide owners with significant benefits including lower energy costs, smaller size, and lower sound levels;
- All refrigeration system impacts are usually encompassed in the chiller or condensing set so the designer is not concerned with factors such as superheat and sub-cooling.

Limitations

- Limitations are really restricted to location and that relates to potential contamination of air intakes by Legionella bacteria that might be present in the cooling tower basin;
- Extremes of ambient wet bulb limit the ability of cooling towers to reject heat so in areas like Florida, a cooling tower will need to be large and the CW temperature will most probably need to be higher than 90°F.
- Water treatment and corrosion are of greater concern in the open-circuit cooling tower. Chemical or non-chemical water treatment techniques incur continuous expenditure.

ADIABATIC CONDENSERS

Adiabatic condensers are in essence an air cooled condenser but with the ambient air pre-cooled by wetted pads. Ambient air is drawn through the pads to be adiabatically cooled to about 80% to 85% saturation before entering to condenser coil.

Water is re-circulated over the pads when needed and is dumped every night. If ambient conditions are low enough, the water is not used and the condenser is a straight air cooled device.

All refrigeration effects and impacts are the same as for an air cooled solution with the exception that water cooled performance can be achieved from an air cooled solution.

The installation still requires a receiver, but there is no sub-cooling coil provided. Sub-cooling is achieved within the condenser coil in similar manner to a shell and tube condenser. In essence, the condenser coil is larger than it need be to condense the hot gas to liquid. However, this fact makes the receiver an imperative.

Selection criteria are ambient wet bulb and dry bulb, and the desired saturated condensing temperature. The condensing temperature can be the same as a water cooled solution at say 104°F and the ambient wet bulb should be 0.5°K higher than design. Ambient dry bulb has an impact but it is not as great as wet bulb. Dry bulb can be the normal design dry bulb for the geographic region.

Limitations

- The largest adiabatic cooler will reject 250 TR. This equates to the cooling effects to roughly 200 TR (assuming 25% heat of compression). The foot print for a horizontal unit is 7.5m x 2.12m with an access need of 1.2m all around;
- Noise is often a significant problem due the amount of air needed to dissipate the heat. The largest unit available has ten fans and the noise level can exceed 81dBA;
- Fin material for the coils is susceptible to corrosion so that is also a factor in their selection. However, the pre-cooling pads act as a filter and washer to protect the coils. The impact of corrosion is not usually as high as for an air cooled condenser;
- Water is needed but the consumption is minimal;

- Capital cost is higher than water cooled or air cooled solution. However, if the plant size is large enough to need two air cooled condensers, the adiabatic solution is more economical.

Advantages

If there is sufficient real estate available for an air cooled solution and the plant size is less than 200 TR, an adiabatic condenser will provide the best energy result of all heat rejection methods.

Water cooled performance is achieved without the need for water treatment.

Economic Analysis

The following matrix details indicative capital costs for each method based upon a 200 TR chilled water plant:

	Air Cooled	Closed Circuit	Evaporative	Water Cooled	Adiabatic
Chiller	$110,000	$110,000	$110,000	$140,000	$110,000
CW Pumps		$10,000		$10,000	
CW Pipework		$50,000		$50,000	
Refrigeration pipework	$50,000		$50,000		$50,000
Water treatment		$8,000	$8,000	$12,000	
Condenser	$60,000		$56,000		$70,000
Cooling Tower		$80,000		$25,000	
Electrical	$20,000	$30,000	$30,000	$30,000	$20,000
Totals	$240,000	$288,000	$254,000	$267,000	$250,000

Obviously there is little difference between the options with air cooled as the less cost and closed circuit cooler as the highest. The selection is then based upon other impacts such as energy, water and real estate.

Environmental

Main environmental impacts are energy and water consumption. The following matrix indicates potential environmental impact:

	Air Cooled	Closed Circuit	Evaporative	Water Cooled	Adiabatic
Energy	110%	105%	105%	100%	100%
Water	0%	80%	80%	100%	25%
Chemicals	0%	50%	50%	100%	0%

Note, the above analysis is indicative and the actual consumption need to be assessed for each site.

Course Summary and Recommendations

The HVAC system required for cooling has two functions to perform:

- Cooling of air and dehumidification
- Heat rejection

The cooling of air can be accomplished by direct expansion of refrigerant in cooling coils (DX system) or through chilled water passing through a cooling coil.

DX system are designed to condition a single space or a portion of space from a location within or adjacent to the space. Such a system is also known as local self-contained system. DX systems could be applied to small or medium sized building requiring approximately 100 TR or less of refrigeration. The standard window, package and split units are typical examples of DX systems.

Chilled water systems are designed to condition several spaces from one base location. Chilled water is produced in a refrigeration plant located at one central location and is pumped to multiple air handling units (AHU) cooling coils scattered all over the facility. Use of central chilled water system shall be considered when air-conditioning two or more adjacent buildings or when the refrigeration loads are greater than 100 TR.

Heat rejection by the refrigeration equipment is accomplished in condensing unit that can either be air-cooled or water-cooled.

Air cooled chillers are favored over the water cooled systems under following circumstances:

- Smaller system capacity requirement typically below 200 TR;
- Where water is scarce or quality water is not available;
- Where the system is not required to operate 24 hours;

- Where the system is not to be located in or around noise restricted areas;
- Where there is adequate and accessible roof top or ground space for the system equipment;
- Where sitting of cooling tower is restricted due to Legionella risk minimization constraints;
- There may be statutory requirements for health and safety that may not permit use of cooling towers in certain areas;
- A high humidity climatic condition in the tropical areas where the effectiveness of the cooling towers is significantly reduced.

Water-cooled chillers are generally favorable over the air-cooled systems under the following circumstances:

- Larger system capacity requirement typically above 200 TR;
- Where the system is required to operate 24 hours;
- Where there is limited roof top or ground space for the system equipment;
- Where plenty of good quality water is available;
- Where noise minimization and aesthetics are of relative importance;
- Where the ambient conditions are dry and not humid.

Although there is no single criterion to base your choice for the heat rejection, the present trend leans towards the use of air-cooled condensers. Each system is considered to be more favorable than the other over a certain range of plant capacity. The selection should be based upon the life cycle costs, energy, water and real estate.