PDHonline Course M117 (2 PDH)

Selection Tips For Air-Conditioning Cooling Systems

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Course Content

PART I - HVAC COOLING SYSTEMS

A HVAC system may be defined as an assembly of components with a particular structure and a defined function. There are literally dozen or hundred of ways in which basic HVAC components may be assembled into systems. The most common air-cooling systems are either direct expansion (DX) type or the chilled water type. Both these systems result in dehumidification as a result of cooling.

Direct Expansion (DX) systems:

In DX systems, the air is cooled with refrigerant passing through the tubes of the finned cooling coil. The Figure-1 below provides a conceptual view of a DX air-conditioning system.

In this figure, 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 a 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.

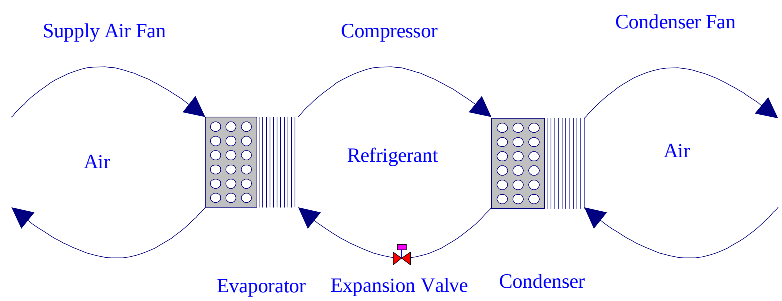

FIGURE -1
DX SYSTEM

Window air-conditioners, package units and split systems are typical examples of DX systems. These comprise of a hermetic sealed compressor/s, evaporator (cooling coil fabricated out of copper tubes and aluminum fins), a supply air fan, filter and a condensing unit. DX systems are essentially the factory assembled self-contained units and are also known as local systems.

The application and unit capacity ranges are as follows:

- Room air conditioner (capacity range of 0.5 to 3 TR per unit, suitable for an area of not more than 1000 square feet)
- Packaged unit integral air-cooled condenser (capacity range of 3 to 50 TR, suitable for a maximum an area of 1000 – 10000 square feet)
- Split system with outdoor air-cooled condenser (capacity range of 0.5 to 50 TR, suitable for an area of 100 – 10000 square feet)

(A ton of refrigeration (1TR) signifies the ability of an air-conditioning equipment to extract heat @ 12000 Btu/hr)

Note: Each building is different and the design conditions differ greatly between regions to region. On hotter & humid regions the cooling requirement may be as high as 150 sqft/TR and in cooler places it could be as low as 500 sqft/TR. For comfort applications, it is reasonable to assume a figure of 200 sqft/TR as a rule of thumb for a preliminary estimation in absence of heat load calculations.

DX system operating in reverse vapor compression cycle is classified as Heat pump. Through an addition of a special control valve, heat flow in mechanical refrigeration loop can be reversed so that heat is extracted from outside air and rejected into the building. Such a facility is required during winter season to heat the indoor using the same physical components. Due to added heat of compression, the efficiency of heat pump is higher compared to the cooling cycle.

Chilled Water Systems:

In chilled water system the air is cooled with chilled water passing through the tubes of a finned coil (cooling coil). Chilled water systems are further categorized as air-cooled or water cooled system depending on how the heat is rejected out of the system. The Figure-2 below provides a conceptual view of chilled water air-conditioning system with air-cooled condenser.

The figure below 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.

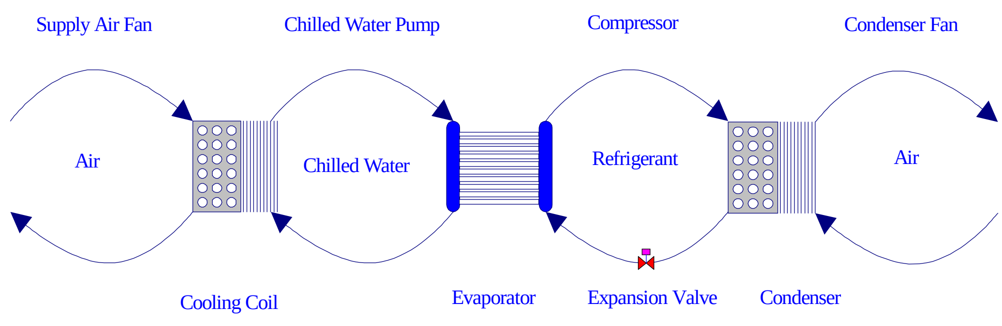

FIGURE -2
CHILLED WATER SYSTEM WITH AIR -COOLED CONSENSER

The Figure-3 below provides a conceptual view of chilled water air-conditioning system with water-cooled condenser.

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.

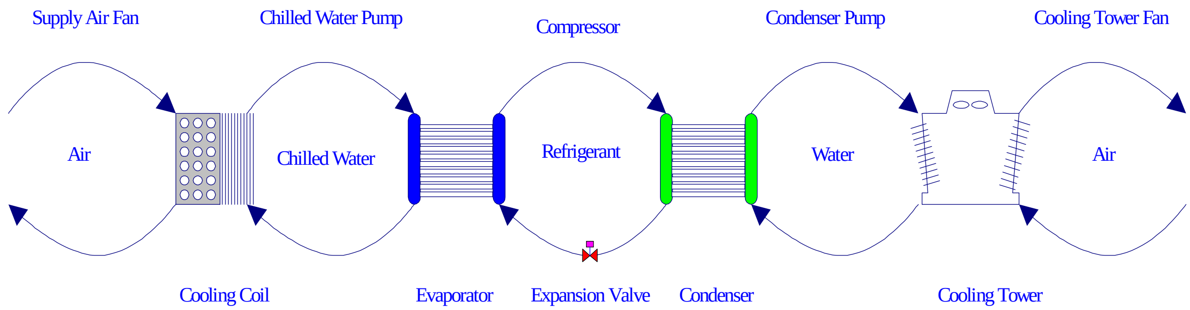

FIGURE -3
CHILLED WATER SYSTEM WITH WATER COOLED CONDENSER

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 from the cooling tower.

The chilled water system is also called central air conditioning system. This is because the chilled water system can be networked to have multiple cooling coils distributed through out a large or distributed buildings with the refrigeration equipment (chiller) placed at one base central location.

Chilled water systems are typically applied to the large and/or distributed areas. (Capacity range of 20- 2000 TR, 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 and central systems is critical from a mechanical, architectural and energy management perspective. Lets 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 an area of a building that 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 areas with large glazing & exposure are prone to larger solar radiation. Such areas shall experience higher heat load than the indoor spaces and must be separately controlled.
- In a commercial office building, a room 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 demands different indoor conditions than the rest of areas and thus shall be treated as a separate zone.
- A control room or processing facilities in industrial set up may require a high degree of 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 is very much an architectural responsibility, as it requires an understanding of building function and schedules.

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

1. The control of an HVAC system is critical to its successful operation. The capacity control in DX system is most commonly accomplished by cycling the compressor on and off in response to signal from 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. Serving a single zone, the DX system will have only one point of control – typically a thermostat. There are solutions to the problem, such as placing a reheat or introducing variable volume but it works against energy conservation and may have problems with the indoor air quality perspective. 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. Multiple evaporators in DX system are not recommended, as precise refrigerant flow to the evaporators is difficult to achieve. Each DX system is thus local self-contained unit consisting of its own compressor/s, evaporator coil, fan, condensing unit and filtration unit. For large buildings consisting of multi-zones, DX system may be viewed as collection of independent units placed at different locations in a distributed network with each unit working in isolation.

Depending upon the capacities required and areas served the DX system could be window 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

<u>Factors favoring DX system:</u>

- Available as factory standard units and offer low capital costs.
- Offer short delivery schedules and generally available off the shelf.
- Easy to install and replace.
- All the controls are integral to the machine.
- Compact and require a smaller footprint than alternatives. The condensing unit could be mounted on the roof or located outside.
- Cooling unit is available in wide variation of floor, wall as well the ceiling suspended units.
- Installation flexibility where space is limited.
- Units come with energy efficiency star labels.

<u>Other views favoring DX systems on a larger scale</u>

- DX systems tend to be distributed for a larger building that provide more reliability; a building conditioned using local systems may have a dozen or hundred of individual and independent units located through out 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.
- 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.
- As a self contained system, a DX system may provide greater occupant comfort through totally individualized control options, for instance if one room needs heating while an adjacent one needs cooling, two local systems can respond without conflict.

<u>Limitations of DX system:</u>

- Local DX systems cannot benefit from economies of scale. Capital costs and the operating costs tend to be higher for larger setups requiring approximately 100 TR or more.
- 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.
- The coefficient of performance (COP) of a refrigeration system increases with capacity. Since the localized DX units are smaller in size, the COP is low.

- 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.
- 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 package units generally 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 are generally available with fan static pressure limits of 2 to 3 inch water gauge pressure that may not be sufficient to cope up the resistance of special filtration needs.
- 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 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.
- A limitation of approximately ~120 ft for maximum separation between compressor and cooling coil applies to all DX installations. 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.

<u>Applications:</u>

- The DX systems are suitable for small or medium sized buildings free of multiple thermal zones and demanding 100TR or less of air-conditioning. For big areas such as Wal-Mart store requiring say 200TR of refrigeration, DX system may be viewed as 4 units of 50TR each subject to availability of space and aesthetics.
- DX systems are more effective for the services requiring low temperature and low humidity for sensitive areas. 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 (window, split or package/unitary units) can be applied for augmenting the HVAC needs in the existing central HVAC systems necessitated due to expansion or addition of more equipment.
- DX systems can be applied along with central chilled water system for areas requiring 24hrs operation such as server rooms, data centers etc.

PART III - KEY FACTORS IN SELECTION OF CHILLED WATER CENTRAL AIR-CONDITIONING SYSTEMS

Chilled water systems can be categorized truly as the central air-conditioning systems. Chilled water is produced at one base (centralized) location and is distributed to multiple air-handling units (AHU's) containing cooling coils placed at different locations. All the components of the air-conditioning system form a network.

Capacity control in chilled water systems is usually achieved through modulating the chilled water flow through the cooling coils. This allows multiple coils to be served from a single chiller without compromising control on any individual unit.

<u>Factors favoring Central chilled water systems:</u>

- Central chilled water system allows major equipment components to be isolated in mechanical room.
- 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 and are tailor made to suit the design requirements i.e. air delivery and refrigeration capacity.
- Central systems provide opportunity for economies of scale and results in low capital and operating costs.
- Larger capacity refrigeration equipment is more energy efficient than the small capacity equipment.
- 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.

<u>Concerns about central system:</u>

- 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, can not 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 IV - FACTORS DETERMINING THE HEAT REJECTION SYSTEM

(Air-cooled v/s Water-cooled Condensers)

The air-conditioning installations working as the central chilled water system use an evaporator for chilled water generation and condenser for heat rejection. The variants available in the machine require the condenser to be either air-cooled or water-cooled. Considering all other factors laid out above are balanced, the selection of the air-cooled or water-cooled variant depends primarily on the availability of quality water, operation duty/ nominal capacity, space requirements, initial first cost and the operating costs.

Comparison

Parameters	**Air-cooled Condensers**	**Water-cooled Condensers**
Water loss	Nil	High
Operation Duty & Nominal Capacity	Multiple condensers required above 50 TR cooling capacity	Single condenser combination available for all sizes.
Space Requirements	Low (high above 200 TR)	Low
Energy Efficiency Ratio (EER)	Low	High
Initial Cost	Low	High
Operating Costs	Low	High
Maintenance	Low	High
Seasonal de-rating	High	Low

Analysis

1. 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. Air-cooled condenser 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 gallon. Off course the costs shall be significantly higher with higher HVAC capacities.
2. The quality of water does matter. Ozone treatment or automatic biocide dosage shall be required to limit the growth of Legionella bacteria associated with cooling towers.
3. Air-cooled condensers have a lower initial cost due to lower number of components. Unlike water cooled condensers, air cooled condensers do not require a cooling tower, associated piping, pumps and auxiliaries. With lesser components the associated civil costs also tend to be low.
4. The operation costs of an air-cooled condenser system are lower because of the lower number of power driven auxiliaries and the zero water treatment costs. However COP of air-cooled refrigeration chiller is low compared to water-cooled

machines and the operating economics reverse for unit capacity exceeding 200TR.

5. The air-cooled machines are easy to install and takes lower space compared to water-cooled machines. The space requirements for air-cooled machines however increase significantly over water-cooled machines for nominal capacities above 200 TR.
6. Water-cooled machines do 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.
7. Air-cooled condensers are restricted by distance separation and the installation height differential between the chiller 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 chiller.

Circumstances favoring Air-cooled Systems

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.

Circumstances favoring Water-cooled Systems

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 noise minimization and aesthetics are of relative importance

The present trend leans towards the use of air-cooled condensers. Results from recent generic studies on comparative life cycle costs of air cooled and water cooled systems indicate that each system is considered to be more favorable than the other over a certain range of plant capacity. As a guide, conclusions could be generalized and summarized as follows:

Capacity Range (TR)	Favorable System
40 to 200	Air-cooled chilled water system (explore the pros and cons of using multiple DX systems if possible)
200 and above	Water-cooled chilled water system

Course Summary

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 condensers offer greater advantages over water-cooled condensers up to 200 TR. Above this the water cooled condensers are more economical on life cycle basis.