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Air-Cooled Condensers

Types • Ratings • Design • Construction • Installation • Maintenance

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Air-cooled condensers, also referred to as “fin-and-tube” condensers, are probably the most visible component in an aircooled air conditioning system, be it a room or packaged airconditioner or a packaged chiller. While the evaporator is the component in which heat is absorbed, the condenser is the point of heat rejection in an air conditioning or refrigeration system (**Fig.1**). As the name suggests, the air-cooled condenser uses air to extract the sensible heat and the latent heat of condensation released by the refrigerant during condensation. The refrigerant from the compressor enters the condenser as hot superheated gas and leaves it (usually) as subcooled liquid to continue the refrigerant cycle.

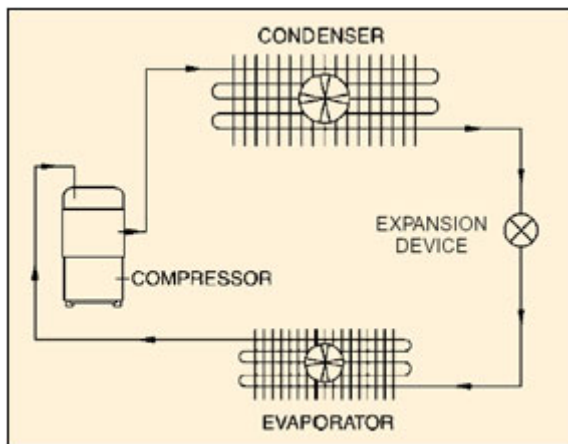


Figure 1 : Basic airconditioning system

Advantages & Disadvantages of Air- Cooled Condensers

Air-cooled condensers are cooled by ambient air and no water is required as the cooling medium. This is a major advantage in regions where water is scarce. There is also no need for a cooling tower and condenser water pump.

Air-cooled condensers have less operational problems such as trapping of oil and require a relatively small quantity of refrigerant in the system in comparison to shell and tube watercooled condenser systems.

On the other hand, air-cooled condensers operate at a greater condensing temperature than watercooled condensers; hence the compressor (and the refrigeration system) delivers 15 to 20% lower capacity. Therefore one has to use a larger compressor. At the same time, the compressor consumes greater power. Hence the air-cooled system has a lower overall energy efficiency.

Types & description of Air- Cooled Condensers

Air-cooled condensers come in a wide variety of shapes and sizes, square or rectangular, flat or bent, in capacities of a few BTUH to hundreds of thousands. Most air-cooled condensers are cooled by one or more condenser fans which blow air across the condenser coil to promote convective heat transfer. The aircooled condenser may be part of a unitary system such as a window airconditioner, a stand alone unit as used with packaged airconditioners or compressor-cooler units (**Fig. 2**) or mounted in a cabinet along with the compressor to form a condensing unit (**Fig.3**) as used in split-system airconditioning and refrigeration systems.

The fans used commonly are axial flow, propeller fans, which are capable of moving large volumes of air, while consuming only 0.08 to 0.15 kW per ton of refrigeration. Since,

these fans develop low static pressure of 6 to 10 mm (water gauge), condenser coils are designed with a large face area, but limited to a few rows in order to minimize the resistance to air flow offered by the coil. Condenser air flows lie in the region of 600 to 1000 cfm per ton at face velocities of 400 to 800 fpm.



Figure 2 : Remote air-cooled condenser
Photo courtesy of York Corp.

The condenser coils used with small and medium split system airconditioners have a relatively large face area and only 1 or 2 rows. This enables the use of low static pressure, low power and hence less expensive fans. Also, the row "effectiveness" or contribution of each succeeding row falls off progressively for every additional row. Hence, limiting the number of rows yields a cost-effective coil design. Noise is increasingly becoming an important environmental factor. Therefore, it is desirable to use large diameter, low speed fans to reduce fan noise. In order to minimise the footprint while using large face area coils, they are bent into L, C or D shapes. **Fig. 3** shows a condensing unit with a C - shaped condenser coil.

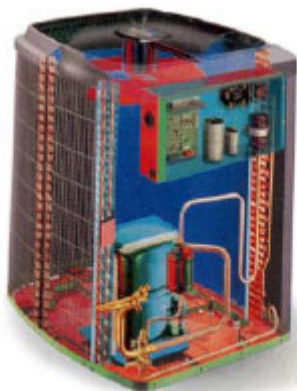


Figure 3 : Air-cooled condensing unit

Centrifugal fans, which are capable of developing higher static pressure, are occasionally used with air-cooled condensers which have to be located indoors or in the basement, so that the hot discharge air off the condenser coil can be ducted out.

Air-cooled condensers are designed for either draw thru' or blow thru' air flow (**Fig.4**). Both types have their pros and cons. With draw thru' design, the face velocity across the coil is more uniform and the coil is more effectively utilised. However, the hot discharge air off the condenser coil flows over the fan and the drive motor, which have to withstand the hot air temperature. In blow thru' designs, the fan and drive motor have ambient air flowing over them. But the face velocity across the coil is less uniform than in the draw thru' design.

There is a pressure drop of refrigerant as it flows through the coil designs tubes of the coil. The coil is therefore broken into multiple circuits in parallel or tree configuration, in order to reduce the pressure drop. The internal pressure drop in a condenser corresponds to about 1.5°C (3°F) change in saturated temperature, i.e. about 10 psi for refrigerant R-22.

A separate pressure vessel called a “receiver” is sometimes used after the condenser coil when it is necessary to store refrigerant during prolonged shutdown.

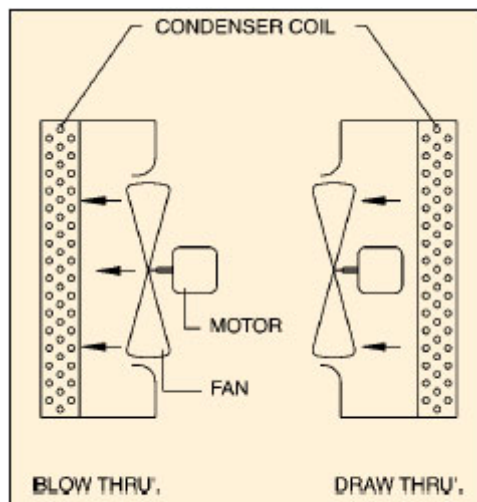


Figure 4 : Blow Thru' & Draw Thru' coil designs

Static condensers

Small appliances such as refrigerators, bottle coolers, freezers and small water coolers, where the heat rejection is limited to about 300 W (1000 Btuh) use static condensers. It comprises a serpentine copper or steel tube, which may have steel wire fins brazed to it and located outside the appliance. However, the modern trend is to embed it on the inside wall of the refrigerator or freezer cabinet so that the entire cabinet wall acts as one large fin. It also keeps the cabinet wall warm and free from condensation.

Ratings & Selection

Condensers are rated in terms of total heat rejection (THR), which is the total heat removed in desuperheating, condensing and subcooling the refrigerant. The total heat rejection is equal to the energy absorbed at the evaporator plus the work input to the compressor. The THR is also the product of the refrigerant mass flow and the enthalpy difference between the refrigerant vapour entering and refrigerant liquid leaving the condenser coil. Condensers are also frequently rated in terms of net refrigerating effect (NRE), assuming a certain heat rejection factor depending on whether the compressor is an open type or hermetic.

In an air-cooled condenser, the refrigerant loses heat by desuperheating, condensing and subcooling. The desuperheating and subcooling zones occupy 5 to 10% each of the condensing surface area, depending on the entering superheated refrigerant vapour and the leaving refrigerant liquid temperatures. The “condensing” zone occupies 80 to 85% of the coil area and takes place at constant temperature (Fig.5). Some condenser coils are provided with integral subcooling passes at the bottom of the coil to enhance subcooling. Overall system capacity increases about 0.5% for every degree F subcooling at the same suction and discharge pressures.

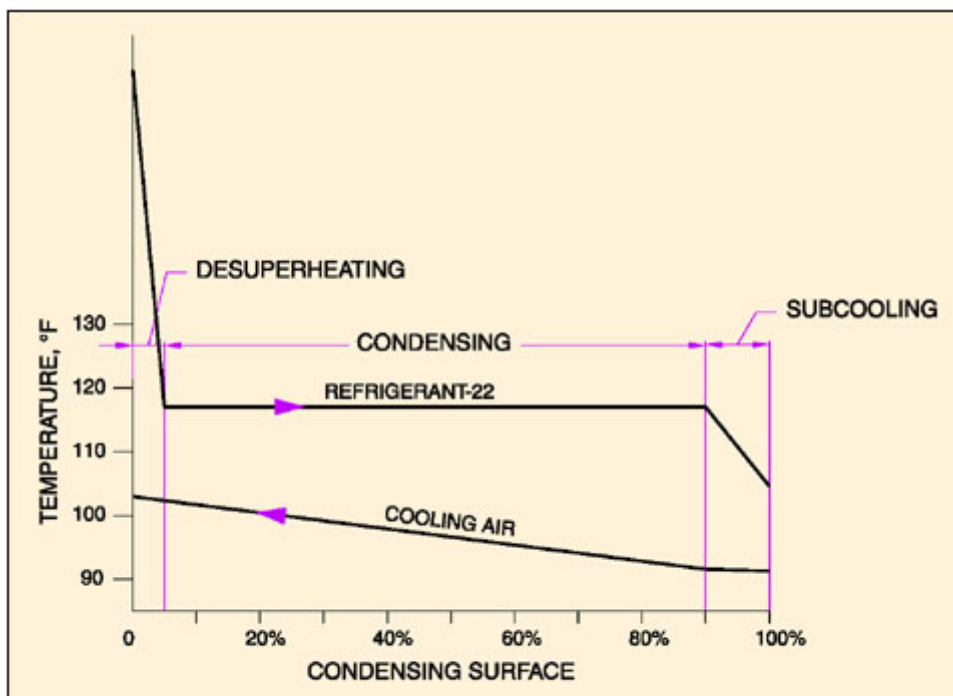


Figure 5 : Temperature curves of refrigerant R-22 and cooling air in an air-cooled condenser

The heat rejection capacity of an air-cooled condenser is proportional to the condenser temperature difference (TD), which is defined as the difference in saturated condensing temperature (corresponding to the refrigerant pressure at the inlet) and the air intake dry bulb temperature. Air-cooled condensers are rated at a specific TD related to the

evaporating temperature of the refrigeration system. Typical TD values are 20'° to 30°F for high temperature systems (airconditioning applications), 15°to 20°F for medium temperature systems (such as water coolers) and 10°to 15°F for low temperature applications (refrigerators and freezers).

Heat Transfer

The rate of heat transfer, q from an air-cooled condenser is given by the standard expression: $q = U A (t_i - t_o)$

Heat transfer takes place sequentially from the refrigerant to the inside wall of the tube, through the tube wall, to the outside wall of the tube and to the ambient air flowing over the coil. Hence, the overall heat transfer coefficient, U is a function of the tube inside and outside film coefficients, the thermal conductivity of the tube material, k and the inside and outside areas of the tube, and may be expressed by the following equation:

$$\frac{1}{U_o A_o} = \frac{1}{U_i A_i} = \frac{1}{h_o A_o} + \frac{t}{k A_m} + \frac{1}{h_i A_i}$$

The outside fluid, to which heat is being transferred, is air, whose properties are such that the outside film coefficient, h_o is very much lower compared to the inside (refrigerant side) film coefficient, h_i . Therefore, the air side (outside) resistance to heat transfer, $1/h_o A_o$ is relatively much higher than the refrigerant side (inside) resistance, $1/h_i A_i$. In order to decrease $1/h_o A_o$, the area A_o is usually increased by using fins.

The air-side area of a fin and tube condenser is composed of a prime area, A_p (which is the area of the tube between the fins) and the extended area, A_e (which is the finned surface area). The temperature of the fin is at the tube outside temperature at the point of contact with the tube and lower (just above the air temperature) at the edge of the fin. This gives rise to the concept of "fin effectiveness", n , which is defined as the ratio of the actual rate of heat transfer to that which would be transferred if the entire fin were at the tube temperature.

Hence the expression $\frac{1}{h_o A_o}$

in the above equation may be substituted by

$$\frac{1}{h_f (A_p + n A_e)}$$

where h_f is the air-side coefficient.

A precise prediction of h_f when air flows over the finned tubes is complicated because the value is a function of geometric factors, such as the fin spacing, the spacing and

diameter of the tubes, and the number of rows deep. Usually, the coefficient varies approximately as the square root of the face velocity of the air. A rough estimate of the air-side coefficient, h_f can be computed from the equation $h_f = 38V^{0.5}$, where V is the face velocity across the coil.

In practice, it is cumbersome to design coils in this manner. Standard coil manufacturers publish a set of curves or tables giving the THR or NRE for different condensing temperatures and a given TD. Condensers are selected by matching the THR effect of the condenser with the total heat rejection, ie, cooling capacity plus power input, of a particular compressor.

Proprietary software Proprietary software packages are also available to design or simulate the performance of an aircooled condenser.

Construction and Manufacture

Figure Air-cooled condenser coils (**Fig.6**) are usually constructed from a bank of copper tubes expanded into a stack of aluminium fins, 0.12 to 2 mm thick. Endplates (or tubesheets) are provided at either end of the coil to complete the coil assembly. In large coils, Top and Bottom plates are also provided, which are bolted to the Endplates for additional rigidity. Copper tube of 7 mm, 9.5 mm (3/8"), 12.7 mm (1/2 ") or 15.9 mm (5/8") is commonly used for small, medium and large-sized coils. Multiple tubes are assembled into a stack of fins, which have holes pre-punched in a fin press. The holes in the fins have collars extruded on to them during the fin punching operation, which prevent telescoping of the fins during the coil expansion and provide the desired fin spacing (which usually varies from 2.5 to 8 fins / cm). Large coils have multiple circuits with a hot gas header and a liquid header brazed on to them.

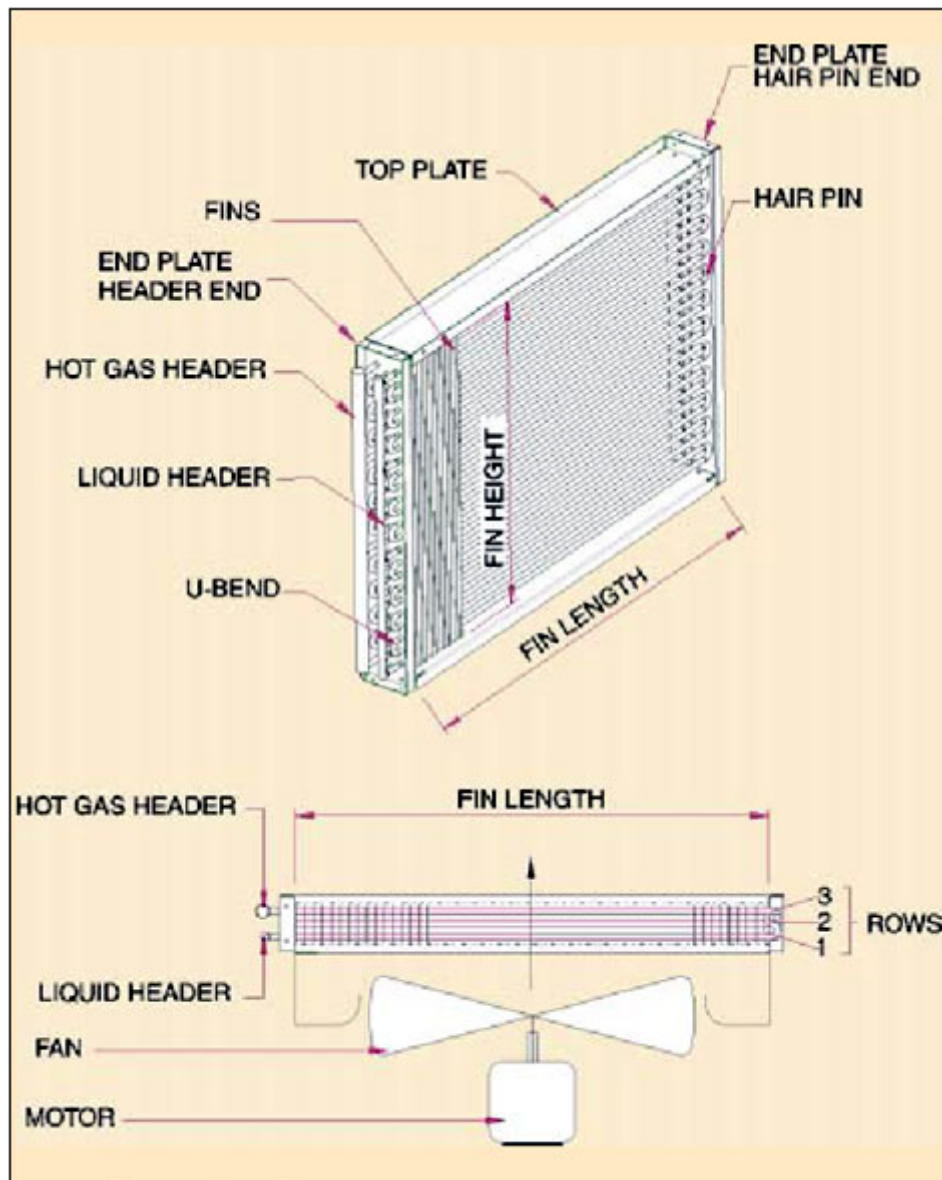


Figure 6 : Air-cooled condenser nomenclature

The fins are provided with various surfaces such as flat, corrugated, sinusoidal and so on. The last decade has seen the use of louvred or slit fin coils (**Fig.7**), which when used with inner grooved or rifled tube, enhance the condenser capacity by 15 to 25%.

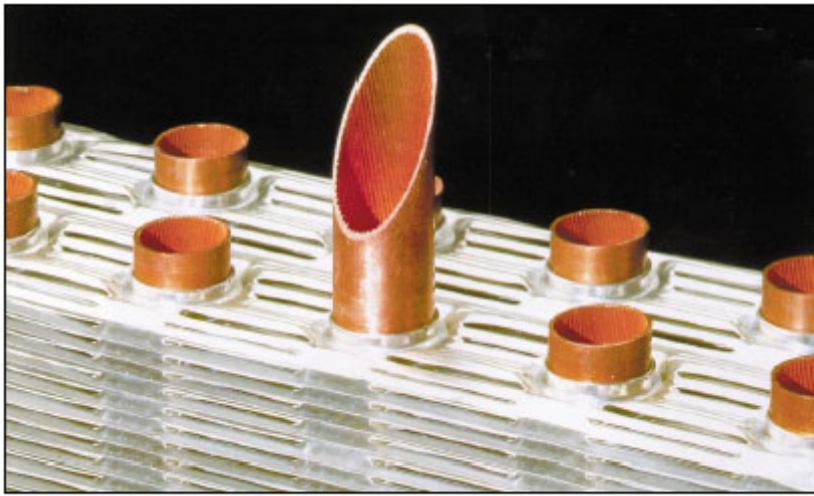


Figure 7 : Louvered Fin and Inner Groove tube coil

A typical coil manufacturing line consists of a decoiling, straightening and tube cut-off station, hairpin and U-bend benders, a high speed mechanical fin press, coil assembly stations, vertical or horizontal coil expanders, brazing stations and pressure testing for leaks. Copper tube is fed in the form of a level wound coil, which is decoiled and straightened and cut off to the required length. The straightened tubes are then formed into hairpins, which are manually inserted into a stack of fins, which have been previously punched on the high speed fin press. Endplates are added at both ends of the coil, after which the tubes are expanded by means of "bullets" in the mechanical expander to provide an interference of 100 to 150 microns with the holes punched in the fins. With the slight increase in tube diameter during expansion, the coil shrinks by about 3% of its length, for which due allowance has to be made at the tube cut-off stage. Ubends and headers are brazed on to complete the coil assembly. It is then pressurised to 1.25 times the maximum operating pressure and tested for leaks by immersing it in a shallow tank of clean, lukewarm water.

In corrosive or salty environments, the aluminium fins are virtually "eaten" away over a period of time. One remedy is to use all copper coils, which may be further tinned to enhance their corrosion resistance. A cheaper alternative is to use epoxy or vinyl coated aluminium fins. A more expensive method is to give a baked epoxy coat over the entire coil. One such patented process is known as "Heresiting". Several proprietary chemical sprays are also available; these may be sprayed over the condenser coil at site and provide some degree of corrosion protection.

All aluminium coils, (commonly used in car airconditioners) with both fin and tubes of aluminium, are also manufactured to reduce material cost. Because of the difficulty of joining aluminium tube (unlike copper tube), special processes such as ultrasonic soldering

have to be used in their manufacture. They are supplied with aluminium to copper tube joints at either end for ease of assembly into the system.

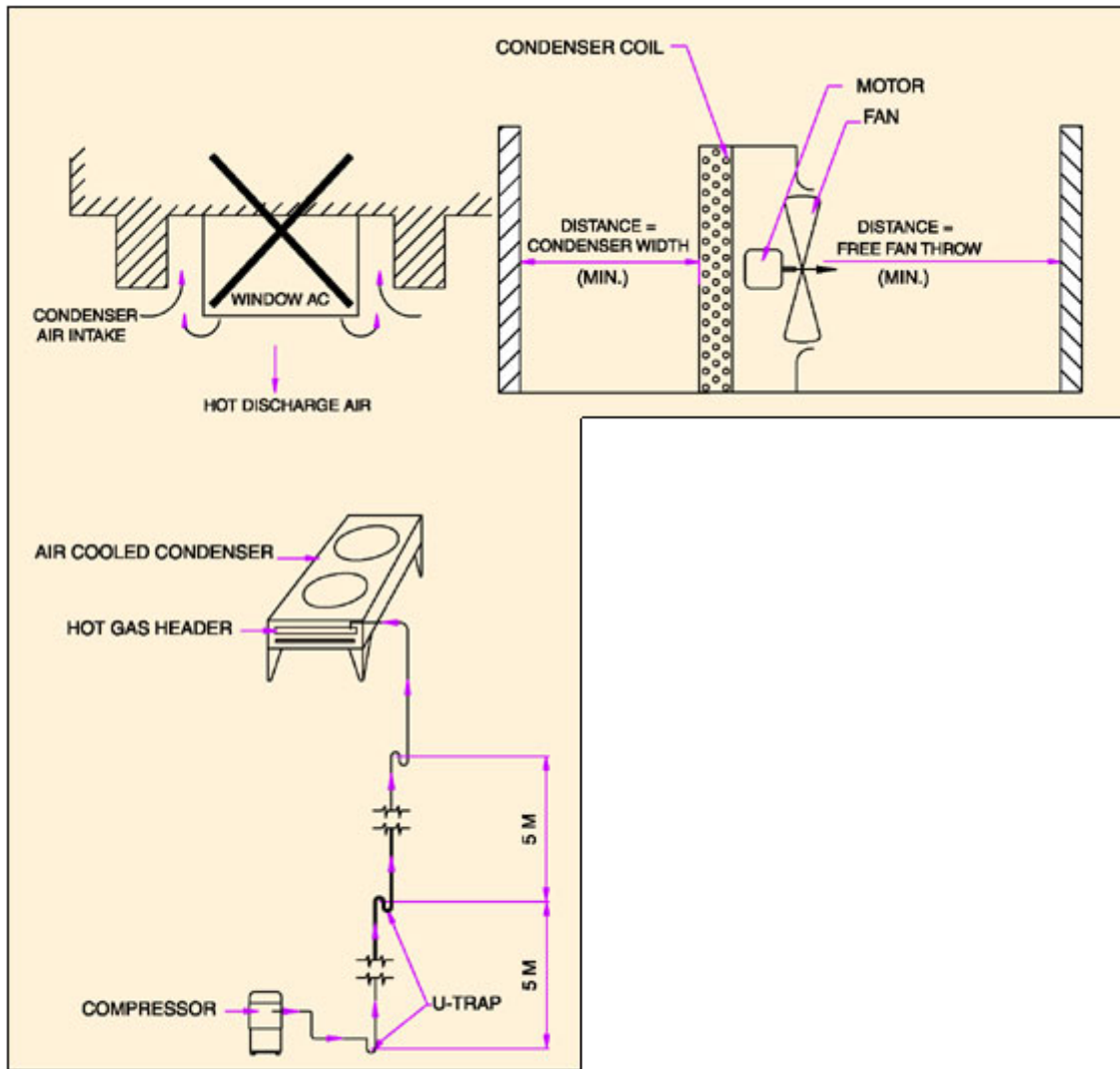


Figure 8 : Air-cooled condenser installation

Installation

Aircooled condensers should be installed in such a way that there is no obstruction or resistance to air flow either on the air intake or on the air discharge side (**Fig.8**). The condenser should not be placed too close to a wall or a ceiling which might obstruct or affect the air flow through the condenser. The air discharging from the condenser should also not "short cycle" or get partly sucked back into the condenser along with the entering air. The obstruction on the discharge side is more critical and should be much farther away since the condenser fan should not "see" any additional resistance to air flow because of the obstruction.

Very often one notices window airconditioners installed in a narrow niche provided by the architect in the outer wall of a building in such a way that the air intake at the sides of the unit is severely restricted. The condenser starves for cooling air resulting in high

discharge pressures, loss of cooling capacity and increase in power consumption. Worse, some of the air discharging from the condenser "short cycles" or is sucked back into the air intake raising the effective temperature of the air entering the condenser and consequent loss of performance.

One should also avoid installing an aircooled condenser facing West in such a manner that the hot afternoon sun directly falls on it.

Aircooled condensers with propeller fans should never be ducted to discharge the hot air off the condenser. Since propeller fans develop low static pressure, the resistance offered by the discharge duct will severely restrict the air flow from the fan and starve the condenser of cooling air.

When the air-cooled condenser of a packaged airconditioner or compressor-cooler unit is installed on the rooftop (or several floors above the indoor unit), the following precautions should be taken to prevent the possibility of compressor failure (**Fig. 8**) :

- the compressor discharge line should be bent down to the floor of the unit before routing it upwards towards the condenser. Similarly, the vertical discharge riser from the compressor should be looped above the air-cooled condenser before entering it. If this is not done, the refrigerant in the vertical discharge riser or the hot gas header (of the condenser) may condense during the off-cycle and collect on the compressor discharge valve and seep into the cylinder. When the compressor restarts, it will try to compress refrigerant liquid (instead of vapour), resulting in possible mechanical failure.
- A 'U' trap should be provided in the compressor discharge line near the compressor at the bottom of the discharge riser and at every 5 metres height. These 'U' traps collect condensed refrigerant and oil and prevent them from reaching the compressor discharge valve.
- As an additional precaution, a discharge line check valve may be provided in the discharge line near the compressor.

Head Pressure Control

At low ambient temperatures or under part-load operation, the compressor discharge or head pressure may become too low, which may cause the expansion valve to malfunction. Hence the discharge pressure is artificially raised by fan cycling, i.e., switching off one or more of the condenser fans. Care should be taken so that air is not sucked in through the

orifice of the stationary condenser fan and bypass the condenser coil. Alternately, the condenser fan speed is modulated by means of a solid state electronic controller, which is actuated by a discharge pressure or liquid line temperature sensor. Head pressure control also helps to reduce the total energy consumed by the condenser fan motors.

Operation & Maintenance

In operation, condenser coils get fouled up by dust, lint or grease from a dirty environment or nearby machinery in operation. An excessive fouling up of the condenser coils will raise the operating discharge pressure and may increase compressor power consumption by upto 30%. Simultaneously, there is a loss of cooling capacity, which means that the compressor has to run for longer periods to produce the same cooling. This results in higher energy consumption and lower compressor life.

There are several ways to effectively clean condenser coils. Coils which have only a light buildup of dirt, lint or grease may be cleaned by a brush, vacuum cleaner or compressed air. In case of heavier buildup, it may be necessary to use a mild detergent or cleaning solution. While cleaning, care should be taken to prevent deforming or damaging the condenser fins which might block airflow through the coil and compound the original problem.

References

1. ASHRAE Handbook : HVAC Systems and Equipment
2. W.F. Stoecker & J.W.Jones : Refrigeration & Air Conditioning, McGraw-Hill, 1982.
3. Shan K.Wang : Handbook of Airconditioning & Refrigeration, McGraw-Hill, 1994.
4. Manufacturers' catalogues and literature