# DESIGN AND ANALYSIS OF EFFICIENT HEAT RECOVERY SYSTEM BY REPLACING AIR CONDENSER WITH WATER CONDENSER

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***Abstract*: Air molding is the way toward modifying the properties of air (basically temperature and dampness) to progressively agreeable conditions, regularly with the point of conveying the adapted air to a consumed space, for example, a structure or a vehicle to improve warm solace and indoor air quality. In the most broad sense, cooling can allude to any type of innovation that adjusts the state of air (warming, cooling, (de-)humidification, cleaning, ventilation, or air development).**

**Need to build The C.O.P (coefficient of execution) of the framework utilizing the warmth exchanger with forced air system. Warm contamination need to diminish. Furthermore, Waste warmth is used for helpful reason. By controlling water stream rate in warmth exchanger, refrigerant can be cooled to required degree. The procedures viable recuperation of waste warmth from the condenser in the refrigeration framework by supplanting the air condenser with water condenser is increasingly effective And the acquired high temp water is used to residential use and just as control on modern application, for example, RH controls and concoction forms and used for all boiling water requirements for mechanical and just as home applications. The effectiveness of condenser increments and consequently productivity of refrigeration cycle builds it shows proficiency of the cooling framework increments. Henceforth the productivity of the warmth recuperation framework 13% more effective than general cooling framework.**

**Air dissemination framework execution can bigly affect in general HVAC framework productivity. Subsequently, air appropriation frameworks face various compulsory measures and prescriptive necessities. Conduit proficiency is influenced various parameters like perspective proportion, area, protection, spillages and so forth. The report outfits in detail of the impact of these parameters and gives a nitty gritty structure of Air Distribution Ducting System with the assistance of Mc Quay Duct Sizer. The undertaking further deals with the steering of the ducting framework for keeping up the progression of air in the whole building.**

***Index Terms*: Heating, cooling, (de-)humidification, cleaning, ventilation, Air Handling Units**

## I. INTRODUCTION

### 1. INTRODUCTION TO AIR CONDITIONER

Air conditioning is the process of modifying the condition of air by removing heat and humidity to achieve more comfortable interior environmental conditions, typically with the aim of distributing the conditioned air to an occupied space to improve thermal comfort and indoor air quality. In general, an air conditioner is a device that removes heat from the air inside a building or vehicle, thus lowering the air temperature and humidity conditions. The cooling is typically achieved through a refrigeration cycle, but sometimes evaporation or free cooling is used.

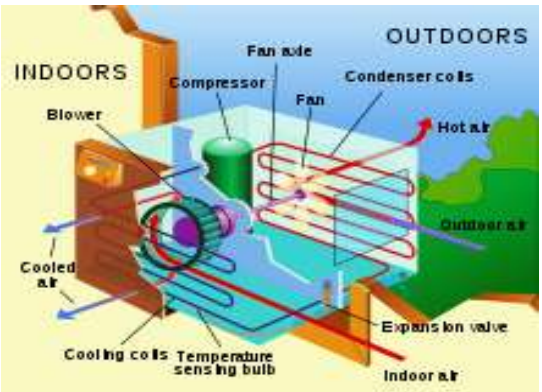


Figure **1.0:** A typical home air conditioning unit.

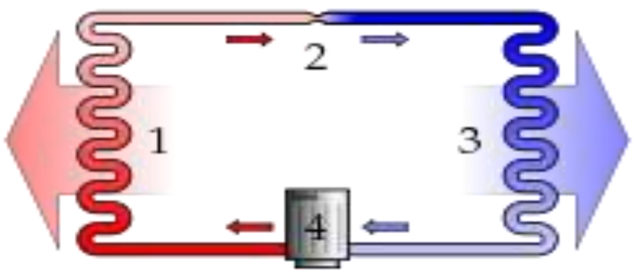


Figure **-1.1:** refrigeration cycle

### 1.1 Principle of working

In the refrigeration cycle, a heat pump transfers heat from a lower-temperature heat source into a higher-temperature heat sink. Heat would naturally flow in the opposite direction. This is the most common type of air conditioning. A refrigerator works in much the same way, as it pumps the heat out of the interior and into the room in which it stands.

This cycle takes advantage of the way phase changes work, where latent heat is released at a constant temperature during a liquid/gas phase change, and where varying the pressure of a pure substance also varies its condensation/boiling point.

The most common refrigeration cycle uses an electric motor to drive a compressor. In an automobile, the compressor is driven by a belt over a pulley, the belt being driven by the engine's crankshaft (similar to the driving of the pulleys for the alternator, power steering, etc.). Whether in a car or building, both use electric fan motors for air circulation. Since evaporation occurs when heat is absorbed, and condensation occurs when heat is released, air conditioners use a compressor to cause pressure changes between two compartments, and actively condense and pump a refrigerant around. A refrigerant is pumped into the evaporator coil, located in the compartment to be cooled, where the low pressure causes the refrigerant to evaporate into a vapor, taking heat with it. At the opposite side of the cycle is the condenser, which is located outside of the cooled compartment, where the refrigerant vapor is compressed and forced through another heat exchange coil, condensing the refrigerant into a liquid, thus rejecting the heat previously absorbed from the cooled space.

By placing the condenser (where the heat is rejected) inside a compartment, and the evaporator (which absorbs heat) in the ambient environment (such as outside), or merely running a normal air conditioners refrigerant in the opposite direction, the overall effect is the opposite, and the compartment is heated. This is usually called a heat pump, and is capable of heating a home to comfortable temperatures (25 °C; 70 °F), even when the outside air is below the freezing point of water (0 °C; 32 °F).

Cylinder unlades are a method of load control used mainly in commercial air conditioning systems. On a semi-hermetic (or open) compressor, the heads can be fitted with unlades which remove a portion of the load from the compressor so that it can run better when full cooling is not needed. Unlades can be electrical or mechanical.

### 1.2 HEAT PUMP

Figure **1.2:** Externally fitted AC unit with heat pump

A heat pump is an air conditioner in which the refrigeration cycle can be reversed, producing heating instead of cooling in the indoor environment. They are also commonly referred to as a "reverse cycle air conditioner". The heat pump is significantly more energy efficient than electric resistance heating. Some homeowners elect to have a heat pump system installed as a feature of a central air conditioner. When the heat pump is in heating mode, the indoor evaporator coil switches roles and becomes the condenser coil, producing heat. The outdoor condenser unit also switches roles to serve as the evaporator, and discharges cold air (colder than the ambient outdoor air).Air-source heat pumps are more popular in milder winter climates where the temperature is frequently in the range of 40–55 °F (4–13 °C), because heat pumps become inefficient in more extreme cold. This is because ice forms on the outdoor unit's heat exchanger coil, which blocks air, flow over the coil. To compensate for this, the heat pump system must temporarily switch back into the regular air conditioning mode to switch the outdoor evaporator coil *back* to being the condenser coil, so that it can heat up and defrost. A heat pump system will therefore have a form of electric resistance heating in the indoor air path that is activated only in this mode in order to compensate for the temporary indoor air cooling, which would otherwise be uncomfortable in the winter. The icing problem becomes much more severe with lower outdoor temperatures, so heat pumps are commonly installed in tandem with a more conventional form of heating, such as a natural gas or oil furnace, which is used instead of the heat pump during harsher winter temperatures. In this case, the heat pump is used efficiently during the milder temperatures, and the system is switched to the conventional heat source when the outdoor temperature is lower.

Absorption heat pumps are a kind of air-source heat pump, but they do not depend on electricity to power them. Instead, gas, solar power, or heated water is used as a main power source. An absorption pump dissolves ammonia gas in water, which gives off heat. Next, the water and ammonia mixture is depressurized to induce boiling, and the ammonia is boiled off, which absorbs heat from the outdoor air. Some more expensive window air conditioning units have a true heat pump function. However, a window unit may only have an electric resistance heater.

### 1.3. History of AIR CONDITIONING SYSTEMS

#### 1.3.1 Evaporative cooling

Since prehistoric times, snow and ice were used for cooling. The business of harvesting ice during winter and storing for use in summer became popular towards the late 19th century. This practice was replaced by mechanical ice-making machines. The basic concept behind air conditioning is said to have been applied in ancient Egypt, where reeds were hung in windows and were moistened with trickling water. The evaporation of water cooled the air blowing through the window. This process also made the air more humid, which can be beneficial in a dry desert climate. In Ancient Rome, water from aqueducts was circulated through the walls of certain houses to cool them. Other techniques in medieval Persiainvolved the use of cisterns and wind towers to cool buildings during the hot season.

The 2nd-century Chinese inventor Ding Huan (fl 180) of the Han Dynasty invented a rotary fan for air conditioning, with seven wheels 3 m (10 ft) in diameter and manually powered. In 747, Emperor Xuanzong (r. 712–762) of the Tang Dynasty (618–907) had the *Cool Hall* (*Liang Tian*) built in the imperial palace, which the *Tang Yulin* describes as having water fan wheels for air conditioning as well as rising jet streams of water from fountains. During the subsequent Song Dynasty (960–1279), written sources mentioned the air conditioning rotary fan as even more widely used. In the 17th century, Cornelius Drebbel demonstrated "Turning Summer into winter" for James I of England by adding salt to water.

#### 1.3.2 Development of mechanical cooling

Figure **1.3.2.1** Three-quarters scale model of Gorrie's ice machine

Modern air conditioning emerged from advances in chemistry during the 19th century, and the first large-scale electrical air conditioning was invented and used in 1902 by American inventor Willis Carrier. The introduction of residential air conditioning in the 1920s helped enable the great migration to the Sun Belt in the United States.

In 1758, Benjamin Franklin and John Hadley, a chemistry professor at Cambridge University, conducted an experiment to explore the principle of evaporation as a means to rapidly cool an object. Franklin and Hadley confirmed that evaporation of highly volatile liquids (such as alcohol and ether) could be used to drive down the temperature of an object past the freezing point of water. They conducted their experiment with the bulb of a mercury thermometer as their object and with a bellows used to speed-up the evaporation.

#### 1.3.3 Electromechanical cooling

In 1902, the first modern electrical air conditioning unit was invented by Willis Carrier inBuffalo, New York. After graduating from Cornell University, Carrier found a job at theBuffalo Forge Company. While there, he began experimenting with air conditioning as a way to solve an application problem for the Sackett-Wilhelms Lithographing and Publishing Company in Brooklyn, New York. The first air conditioner, designed and built in Buffalo by Carrier, began working on 17 July 1902.

Designed to improve manufacturing process control in a printing plant, Carrier's invention controlled not only temperature but also humidity. Carrier used his knowledge of the heating of objects with steam and reversed the process. Instead of sending air through hot coils, he sent it through cold coils (filled with cold water). The air was cooled, and thereby the amount of moisture in the air could be controlled, which in turn made the humidity in the room controllable. The controlled temperature and humidity helped maintain consistent paper dimensions and ink alignment. Later, Carrier's technology was applied to increase productivity in the workplace, and The Carrier Air Conditioning Company of America was formed to meet rising demand. Over time, air conditioning came to be used to improve comfort in homes and automobiles as well. Residential sales expanded dramatically in the 1950s.

In 1906, Stuart W. Cramer of Charlotte, North Carolina was exploring ways to add moisture to the air in his textile mill. Cramer coined the term "air conditioning", using it in a patent claim he filed that year as an analogue to "water conditioning", then a well-known process for making textiles easier to process. He combined moisture with ventilation to "condition" and changes the air in the factories, controlling the humidity so necessary in textile plants. Willis Carrier adopted the term and incorporated it into the name of his company.

Shortly thereafter, the first private home to have air conditioning was built in Minneapolis in 1914, owned by Charles Gates. Realizing that air conditioning would one day be a standard feature of private homes, particularly in regions with warmer climate, David St. Pierre DuBose (1898-1994) designed a network of ductwork and vents for his home*Meadowmont*, all disguised behind intricate and attractive Georgian-style open moldings.This building is believed to be one of the first private homes in the United States equipped for central air conditioning

In 1945, Robert Sherman of Lynn, Massachusetts invented a portable, in-window air conditioner that cooled, heated, humidified, dehumidified, and filtered the air.

### 1.3.4 Refrigerant development


Figure **-1.3.4.1** R-134a hermetic refrigeration compressor

The first air conditioners and refrigerators employed toxic or flammable gases, such as ammonia, methyl chloride, or propane that could result in fatal accidents when they leaked. Thomas Midgley, Jr. created the first non-flammable, non-toxic chlorofluorocarbon gas, *Freon*, in 1928. The name is atrademark name owned by DuPont for any chlorofluorocarbon (CFC),hydrochlorofluorocarbon (HCFC),or hydrofluorocarbon (HFC) refrigerant. The refrigerant names include a number indicating the molecular composition (e.g., R-11, R-12, R-22, and R-134A). The blend most used in direct-expansion home and building comfort cooling is an HCFC known as chlorodifluoromethane (R-22).

Modern refrigerants have been developed to be more environmentally safe than many of the early chlorofluorocarbon-based refrigerants used in the early- and mid-twentieth century. These include HCFCs (R-22, as used in most U.S. homes even before 2011) and HFCs (R-134a, used in most cars) have replaced most CFC use. HCFCs, in turn, are supposed to have been in the process of being phased out under the Montreal Protocol and replaced by HFCs such asR-410A, which lack chlorine HFCs, however, contribute to climate change problems. Moreover, policy and political influence by corporate executive's resisted change Corporations insisted that no alternatives to HFCs existed. The environmental organization Greenpeace solicited a European laboratory to research an alternative ozone- and climate-safe refrigerant in 1992, gained patent rights to a hydrocarbon mix of isopentane and isobutane, but then left the technology as open access. Their activist marketing first in Germany led to companies like Whirlpool, Bosch, and later LG and others to incorporate the technology throughout Europe, then Asia, although the corporate executives resisted in Latin America, so that it arrived in Argentina produced by a domestic firm in 2003, and then finally with giant Bosch's production in Brazil by 2004. In 1995, Germany made CFC refrigerators illegal. DuPont and other companies blocked the refrigerant in the U.S. with the U.S. E.P.A., disparaging the approach as "that German technology." Nevertheless, in 2004, Greenpeace worked with multinational corporations like Coca-Cola and Unilever, and later Pepsico and others, to create a corporate coalition called Refrigerants Naturally! Then, four years later, Ben & Jerry's of Unilever and General Electric began to take steps to support production and use in the U.S. Only in 2011 did the E.P.A. finally decide in favor of the ozone- and climate-safe refrigerant for U.S. manufacture.

### 1.4 Scope of air conditioning systems.

Air-conditioning systems are mainly classified into *comfort* and *process* applications
Comfart application implies home applications. Processes application implies industrial applications which mainly depedent on conditioning systems.

### 1.4.1 Comfort applications.

Comfort applications are mainly focused into constant building environment irrespective of outside environment application. Comfort application are mainly classified into several categories based on applications such as
1. Commercial buildings, which are built for commerce, including offices, malls, shopping centers, restaurants, etc.
2. High-rise residential buildings, such as tall dormitories and apartment blocks.
3. Industrial spaces where thermal comfort of workers is desired
4. Institutional buildings, which includes government buildings, hospitals, schools, etc.
5. Low-rise residential buildings, including single-family houses, duplexes, and small apartment buildings

Women have, on average, than men. Using inaccurate metabolic rate guidelines for air conditioning sizing can result in oversized and less efficient equipment, and setting system operating set points too cold can result in reduced worker productivity  In addition to buildings, air conditioning can be used for many types of transportation, including automobiles, buses and other land vehicles, trains, ships, aircraft, and spacecraft

Figure **1.4.1.1** an array of air conditioner outdoor units

**1.4.2 Domestic use**

New homes constructed in 2011 including air conditioning, ranging from 99% in the South to 62% in the West. In Canada, air conditioning use varies by province. In 2013, 55% of Canadian households reported having an air conditioner, with high use in Manitoba (80%), Ontario (78%), Saskatchewan (67%), and Quebec(54%) and lower use in Prince Edward Island (23%), British Columbia (21%), and Newfoundland and Labrador (9%) In Europe, home air conditioning is generally less common. Southern European countries such as Greece have seen a wide proliferation of home air-conditioning units in recent years.[43] In another southern European country, Malta, it is estimated that around 55% of households have an air conditioner installed. In India AC sales have dropped by 40% due to higher costs and stricter energy efficiency regulations.

**Processes applications**

In Processes applications an important to provide a suitable environment for a process being carried out, regardless of internal heat and humidity loads and external weather conditions. It is the needs of the process that determine conditions, not human preference. Process applications include these:

- Chemical and biological laboratories.
- Clean rooms for the production of integrated circuits, pharmaceuticals, and the like, in which very high levels of air cleanliness and control of temperature and humidity are required for the success of the process.
- Environmental control of data centers.
- Facilities for breeding laboratory animals. Since many animals normally reproduce only in spring, holding them in rooms in which conditions mirror those of spring all year can cause them to reproduce year-round.
- Food cooking and processing areas.

Hospital operating theatres, in which air is filtered to high levels to reduce infection risk and the humidity controlled to limit patient dehydration. Although temperatures are often in the comfort range, some specialist procedures, such as open heart surgery, require low temperatures (about 18 °C, 64 °F) and others, such as neonatal, relatively high temperatures (about 28 °C, 82 °F)

1. Industrial environments.
2. Mining.
3. Nuclear facilities.
4. Physical testing facilities.
5. Textile manufacturing.

Packaged terminal air conditioner (PTAC) systems are also known as wall-split air conditioning systems. They are ductless systems. PTACs, which are frequently used in hotels, have two separate units (terminal packages), the evaporative unit on the interior and the condensing unit on the exterior, with an opening passing through the wall and connecting them. This minimizes the interior system footprint and allows each room to be adjusted independently. PTAC systems may be adapted to provide heating in cold weather, either directly by using an electric strip, gas, or other heater, or by reversing the refrigerant flow to heat the interior and draw heat from the exterior air, converting the air conditioner into a heat pump. While room air conditioning provides maximum flexibility, when used to cool many rooms at a time it is generally more expensive than central air conditioning.

**Split systems**

Split-system air conditioners come in two forms: mini-split and central systems. In both types, the inside-environment (evaporative) heat exchanger is separated by some distance from the outside-environment (condensing unit) heat exchanger.

**Mini-split (ductless) system**

Figure **-1.4.1.2** outside part of a ductless split-type air conditioner

Figure **1.4.1.3** Indoor part of a ductless split-type air conditioner

A mini-split system typically supplies air conditioned and heated air to a single or a few rooms of a building.[32] Mutely-zone systems are a common application of ductless systems and allow up to 8 rooms (zones) to be conditioned from a single outdoor unit. Multi-zone systems typically offer a variety of indoor unit styles including wall-mounted, ceiling-mounted, ceiling recessed, and horizontal ducted. Mini-split systems typically produce 9,000 to 36,000 Btu (9,500–38,000 kJ) per hour of cooling. Multi-zone systems provide extended cooling and heating capacity up to 60,000 Btu's.

Advantages of the ductless system include smaller size and flexibility for zoning or heating and cooling individual rooms. The inside wall space required is significantly reduced. Also, the compressor and heat exchanger can be located farther away from the inside space, rather than merely on the other side of the same unit as in a PTAC or window air conditioner. Flexible exterior hoses lead from the outside unit to the interior one(s); these are often enclosed with metal to look like common drainpipes from the roof. In addition, ductless systems offer higher efficiency, reaching above 30 SEER

The primary disadvantage of ductless air conditioners is their cost. Such systems cost about US$1,500 to US$2,000 per ton (12,000 BTU per hour) of cooling capacity. This is about 30% more than central systems (not including ductwork) and may cost more than twice as much as window units of similar capacity.

An additional possible disadvantage that the cost of installing mini splits can be higher than some systems, although lower operating costs and rebates or other financial incentives—offered in some areas—can help offset the initial expense

**Central (ducted) air conditioning**

Central (ducted) air conditioning offers whole-house or large-commercial-space cooling, and often offers moderate multi-zone temperature control capability by the addition of air-louver-control boxes.

In central air conditioning, the inside heat-exchanger is typically placed inside the central furnace/AC unit of the forced air heating system which is then used in the summer to distribute chilled air throughout a residence or commercial building.

**Portable units**

A portable air conditioner can be easily transported inside a home or office. They are currently available with capacities of about 5,000–60,000 BTU/h (1,500–18,000 W) and with or without electric-resistance heaters. Portable air conditioners are either evaporative or refrigerative.

The compressor-based refrigerant systems are air-cooled, meaning they use air to exchange heat, in the same way as a car or typical household air conditioner does. Such a system dehumidifies the air as it cools it. It collects water condensed from the cooled air and produces hot air which must be vented outside the cooled area; doing so transfers heat from the air in the cooled area to the outside air.

**Portable split system**

A portable system has an indoor unit on wheels connected to an outdoor unit via flexible pipes, similar to a permanently fixed installed unit.

**Portable hose system**

Hose systems, which can be *Monoblock* or *air-to-air*, are vented to the outside via air ducts. The *Monoblock* type collects the water in a bucket or tray and stops when full. The *air-to-air* type re-evaporates the water and discharges it through the ducted hose and can run continuously.

A single-hose unit uses air from within the room to cool its condenser, and then vents it outside. This air is replaced by hot air from outside or other rooms (due to the negative pressure inside the room), thus reducing the unit's effectiveness.

Modern units might have a coefficient of performance of approximately 3 (i.e., 1 kW of electricity will produce 3 kW of cooling). A dual-hose unit draws air to cool its condenser from outside instead of from inside the room, and thus is more effective than most single-hose units.

**Portable evaporative system**

Evaporative coolers, sometimes called "swamp coolers", do not have a compressor or condenser. Liquid water is evaporated on the cooling fins, releasing the vapor into the cooled area. Evaporating water absorbs a significant amount of heat, the latent heat of vaporization, cooling the air. Humans and animals use the same mechanism to cool themselves by sweating.

Evaporative coolers have the advantage of needing no hoses to vent heat outside the cooled area, making them truly portable. They are also very cheap to install and use less energy than refrigerative air conditioners.

**Energy transfer**

In a thermodynamically closed system, any power dissipated into the system that is being maintained at a set temperature (which is a standard mode of operation for modern air conditioners) requires that the rate of energy removal by the air conditioner increase.

This increase has the effect that, for each unit of energy input into the system (say to power a light bulb in the closed system); the air conditioner removes that energy.[26] In order to do so, the air conditioner must increase its power consumption by the inverse of its "efficiency" (coefficient of performance) times the amount of power dissipated into the system. As an example, assume that inside the closed system a 100 W heating element is activated, and the air conditioner has a coefficient of performance of 200%. The air conditioners power consumption will increase by 50 W to compensate for this, thus making the 100 W heating element cost a total of 150 W of power.

It is typical for air conditioners to operate at "efficiencies" of significantly greater than 100%.[27] However, it may be noted that the input electrical energy is of higher thermodynamic quality (lower entropy) than the output thermal energy (heat energy).

Air conditioner equipment power in the U.S. is often described in terms of "tons of refrigeration". A ton of refrigeration is approximately equal to the cooling power of one short ton (2000 pounds or 907 kilograms) of ice melting in a 24-hour period. The value is defined as 12,000 BTU per hour, or 3517 watts.[28] Residential central air systems are usually from 1 to 5 tons (3 to 20 kilowatts (kW)) in capacity.

**Seasonal energy efficiency ratio**

For residential homes, some countries set minimum requirements for energy efficiency. In the United States, the efficiency of air conditioners is often (but not always) rated by the *seasonal energy efficiency ratio (SEER)*. The higher the SEER rating, the more energy efficient is the air conditioner. The SEER rating is the BTU of cooling output during its normal annual usage divided by the total electric energy input in watt hours (Who) during the same period.

**SEER = BTU ÷ (Who)**

This can also be rewritten as:

**SEER = (BTU / h) ÷ W**, where "W" is the average electrical power in Watts, and (BTU/h) is the rated cooling power.

For example, a 5000 BTU/h air-conditioning unit, with a SEER of 10, would consume 5000/10 = 500 Watts of power on average.

The electrical energy consumed per year can be calculated as the average power multiplied by the annual operating time:

**500 W × 1000 h = 500,000 Who = 500 kWh**

Assuming 1000 hours of operation during a typical cooling season (i.e., 8 hours per day for 125 days per year).

## II. SELECTING THE PROPER COMPRESSOR

**DETERMINE THE MINIMUM RPM REQUIRED. ($RPM_{min}$)**

With the compressor model and Required Piston Displacement known, the minimum RPM required can be calculated.

In the example problem, we selected a size 360 compressors with a required Piston Displacement of 20.07 CFM. Therefore:

$RPM_{min}$ = 100 (20.07 CFM / 4.36 $ft^3$/100rpm) = 460 RPM minimum

SELECT AN ACTUAL RPM (RPM)

Using the sheave and V-belt selection tables, pick an RPM slightly above the minimum RPM required just calculated.

In the example problem, we selected a size 360 compressors at a minimum speed of 460 RPM. From a list of available V-belt sheaves, the next higher available speed is 470 RPM.

**CALCULATE THE COMPRESSOR'S ACTUAL PISTON DISPLACEMENT (PD)**

After determining the compressor's actual speed, the actual piston displacement can be calculated.

PD = RPM * ($PD_{100}$) / 100

In the example problem, we selected a size 360 compressors at a speed of 470 RPM. Therefore, the actual Piston Displacement will be:

PD = 470 RPM * (4.36 $ft^3$) / 100 = 20.49 CFM

If the calculated BHP is greater that the rating for the selected model, use a larger size compressor.

In the example problem:

Once the compressor model, RPM and required power have been determined, various compressor options and accessories will need to be considered. The primary concerns are:

| | |
|---|---|
| N | = 1.40 |
| $P_s$ | = 19.16 psia |
| PD | = 20.49 CFM |
| R | = 4.13 |
| BHP | = .00528 ($^{1.40}/_{1.40-1}$) (19.16) 20.49 ($4.13^{(1.40-1)/1.40}$ - 1) |

CALCULATE THE POWER REQUIRED BHP (KW)

= 3.6 BHP

For estimating purposes, the following formulas may be used:

**Material Compatibility**

O-
rings
and

Single-Stage Models $BHP = .00528\ (^{n}/_{n-1})\ (P_s)\ PD\ (R^{(n-1)/n} - 1)$

Two-Stage Models $BHP = .00528\ (^{2n}/_{n-1})\ (P_s)\ PD\ (R^{(n-1)/2n} - 1)$

| | |
|---|---|
| n | Specific heat ratio of the gas |
| Ps | Suction Pressure (psia) |
| PD | Actual Piston Displacement (CFM) |
| R | Compression Ratio ($P_d$ / $P_s$) |

piston ring materials need to be reviewed to ensure compatibility with the gas stream being handled. Although Blackmer compressors use ductile iron as the primary material, a Teflon-Nickel treatment (TNT-12) is available to enhance its corrosion and wear resistance capabilities. Also, a variety of valve materials are available. Suction Valve Unlades

Many compressors will need some type of capacity control system. Suction valve unlades are one method.

Seal (Piston Rod Packing) Configuration

This will depend on degree of leakage control desired and the pressures involved.

1. External Oil Filter
2. For dirty or dusty locations.
3. Extended Crankshaft
4. If a direct drive is to be used.

In the example the gas being handled is Nitrogen, a non-corrosive gas. Standard materials of construction (ductile iron with Buna-N O-rings) could be used. However, Nitrogen is a very dry gas, so the Poly-filled piston rings and a TNT-12 treated cylinder should be considered.

Since the usage rate will vary, a capacity control system will be needed. Suction valve unlades will be used. The double-seal model (HD362) with Type 1 packing will be used. Neither the external oil filter nor an extended crankshaft is needed in this case.

**Selection of thermo static expansion valve (TXV)**

Proper TXV size is determined by the BTU/HR or tons load requirement, the pressure drop across theTXV, and the evaporator temperature. Do not assume that the pressure drop across the TXV is equal to the difference between discharge and suction pressures at the compressor. This assumption could lead to incorrect sizing of the TXV.The pressure at the TXV outlet will be higher than the suction pressure at the compressor because of the frictional losses through the distribution header, evaporator tubes, suction lines, fittings, and hand valves. On rack systems, the EPR valve also adds substantial pressure drop.

The pressure at the TXV inlet will be lower than the discharge pressure at the compressor because of frictional losses created by the length of liquid line, valves and fittings, and vertical lift. The only exception is if the TXV is installed considerably below the receiver and static head built up is more than enough to offset frictional loses. The liquid line should be properly sized for its actual length plus equivalent length due to fitting and hand valves. Vertical lift in the liquid line adds pressure drop and thus static head must be included the pressure drop across the TXV will be the difference between the discharge and suction pressures at the compressor less the pressure drops in the liquid line, through the distributor, evaporator, and suction line.

ASHRAE tables should be consulted for determining pressure drops in liquid and suction line.

Here is the procedure for properly selecting a TXV:

TABLE I. Determine pressure drop across TXV: using the maximum and minimum condensing pressures, subtract the evaporating pressure from each to get the total high-to-low side pressure drop. From these values subtract the other possible pressure losses– piping and heat exchanger losses; pressure drop thru accessories; vertical lift pressure drop; and the pressure drop across the refrigerant distributor.

TABLE II. Consider the maximum and minimum liquid temperatures of the refrigerant entering the TXV and select the correction factors for those temperatures from the table below the capacity ratings. Determine the corrected capacity requirement by dividing the maximum evaporator load in tons by the liquid correction factors.

TABLE III. Select the TXV size from the proper capacity table for the evaporator temperature, pressure drop available, and corrected capacity requirement.

TABLE IV. Select the proper thermostatic charge based on the evaporator temperature, refrigerant, and whether a Maximum Operating Pressure (see MOP section) type charge is needed.

TABLE V. Determine connections and whether an externally equalized model is required. Always use an externally equalized TXV when a distributor is used.

A solid column of liquid refrigerant is required for proper TXV operation. Calculate the pressure drop in the liquid line to determine if there will be enough sub cooling to prevent flash gas. If the sub cooling of the liquid refrigerant from the condenser is not adequate, then a heat exchanger, liquid sub cooled, or some other means must be used to get enough sub cooling to ensure solid liquid entering the TXV at all times. Emerson Climate Technologies has prepared extended TXV capacity tables. These tables can be found in the Emerson catalog. Always select a TXV based on operating conditions rather than nominal TXV capacities.

**We have to consider following things while in selection of evaporator.**

III. The performance aspects of ideal reciprocating compressors with clearance, specifically: Effect of evaporator temperature on system performance at a fixed condenser temperature Effect of condenser temperature on system performance at a fixed evaporator temperature Effects of pressure ratio and type of refrigerant on compressor discharge temperature

IV. The performance aspects of actual compressor processes by considering:
Effect of heat transfer in the suction line and compressor

A. Effects of pressure drops in the suction and discharge lines and across suction and Discharge valves of compressor
Effect of refrigerant leakage

V. Describe various methods of capacity control

VI. Discuss methods of compressor lubrication

**Effect of evaporator temperature:**

The effect of evaporator temperature on performance of the system is obtained by keeping the condenser temperature (pressure) and compressor displacement rate and clearance ratio fixed. To simplify the discussions, it is further assumed that the refrigeration cycle is an SSS cycle.

a) On Volumetric efficiency and refrigerant mass flow rate:

For a, given condensing temperature (or pressure), the pressure ratio $r_{ap}$ increases as the evaporator temperature (or evaporator pressure) decreases. Hence, from the expression for clearance volumetric efficiency, it is obvious that the volumetric efficiency decreases as evaporator temperature decreases. This is also explained with the help of Fig.19.1, which shows the P-V diagram for different evaporator pressures. As shown, as the evaporator pressure decreases, the volume of refrigerant compressed decreases significantly, since the compressor displacement remains same the clearance volumetric efficiency decreases as evaporator temperature decreases. In fact, as explained in the earlier lecture, at a limiting pressure ratio, the volumetric efficiency becomes zero. As the evaporator temperature decreases the clearance volumetric efficiency decreases and the specific volume of refrigerant at compressor inlet $v_{et}$ increases. As a result of these two effects, the mass flow rate of refrigerant through the compressor decreases rapidly as the evaporator temperature decreases

b) On refrigeration effect and refrigeration capacity:

A compressor alone cannot provide refrigeration capacity. By refrigeration capacity of compressor what we mean is the capacity of a refrigeration system that uses the compressor

At a constant condenser temperature as evaporator temperature

Increases the work of compression, $h_c$ (= $h_2$-$h_1$) decreases. This is due to the divergent nature of isentropic in the superheated region. The work of compression becomes zero when the evaporator temperature becomes equal to the condenser temperature ($T_e$=$T_c$)

The power input to the compressor is given by:

As discussed before, for a given clearance ratio and condenser temperature, the volumetric efficiency and hence the mass flow rate becomes zero at lower limiting value of evaporator temperature ($T_e = T_{e,\,lim}$). Since the work of compression becomes zero when the evaporator temperature equals the condenser temperature, the power input to the compressor, which is a product of mass flow rate and work of compression is zero at a low evaporator temperature (at which the mass flow rate is zero). And the power input also becomes zero when evaporator temperature equals condenser temperature

(At which the work of compression becomes zero)

$\mathbf{Q_e = m.q_e}$

The variation of compressor power input with evaporator temperature has a major practical significance. As a mentioned before, there is an evaporator temperature at which the power reaches a maximum value. If the design evaporator temperature of the refrigeration system is less than the evaporator temperature at which the power is maximum, then the design power requirement is lower than the peak power input. However, during the initial pull-down period, the initial evaporator temperature may lie to the left of the power peak. Then as the system runs steadily the evaporator temperature reduces and the power requirement passes through the peak point. If the motor is designed to suit the design power input, then the motor gets overloaded during every pull-down period as the peak power is greater than the design power input. Selecting an oversized motor to meet the power peak is not an energy efficient solution, as the motor will be underutilized during the normal operation. One way of overcoming the problem is to throttle the suction gas during the pull-down so that the refrigerant mass flow rate is reduced and the motor does not pass through the power peak. In multi-cylinder compressors, some of the cylinders can be unloaded during the pull-down so as to reduce the power requirement.

d) On COP and volume flow rate per unit capacity:

As discussed before, as the evaporator temperature increases the refrigeration effect, $q_e$ increases marginally and the work of compression, $h_c$ reduces sharply. As a result, the COP of the system increases rapidly as the evaporator temperature increases.

The volume flow rate per unit capacity, v is given by:

As evaporator temperature increases the specific volume of the refrigerant at compressor inlet reduces rapidly and the refrigerant effect increases marginally. Due to the combined effect of these two, the volume flow rate of refrigerant per unit capacity reduces sharply with evaporator temperature as shown in Fig. 19.5. This implies that for a given refrigeration capacity, the required volumetric flow rate and hence the size of the compressor becomes very large at very low evaporator temperatures.

Effect of condenser temperature:

Atmospheric air is the cooling medium for most of the refrigeration systems. Since the ambient temperature at a location can vary over a wide range, the heat rejection temperature (i.e., the condensing temperature) may also vary widely. This affects the performance of the compressor and hence the refrigeration system. The effect of condensing temperature on compressor performance can be studied by keeping evaporator temperature constant.

On volumetric efficiency and refrigerant mass flow rate:

The effect of condensing temperature on clearance volumetric efficiency and mass flow rate of refrigerant at a constant evaporator temperature as the condensing temperature increases, the pressure ratio increases, hence, both the volumetric efficiency and mass flow rate decrease as shown in the figure. However, the effect of condensing temperature on mass flow rate is not as significant as the evaporator temperature as the specific volume of refrigerant at compressor inlet is independent of condensing temperature.

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On refrigeration effect and refrigeration capacity:

At a constant evaporator temperature as the condensing temperature increases, then the enthalpy of refrigerant at the inlet to the evaporator increases. Since the evaporator enthalpy remains constant at a constant evaporator temperature, the refrigeration effect decreases with increase in condensing temperature

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Effect of heat transfer

Heat transfer from the cylinder walls and piston to the refrigerant vapor takes place during the suction stroke and heat transfer from the refrigerant to the surroundings takes place at the end of the compression. In hermetic compressors, additional heat transfer from the motor winding to refrigerant takes place. The effect of this heat transfer is to increase the temperature of refrigerant, thereby increasing the specific volume. This in general results in reduced volumetric efficiency and hence reduced refrigerant mass flow rate and refrigeration capacity. The extent of reduction in mass flow rate and refrigeration capacity depends on the pressure ratio, compressor speed and compressor design. As seen before, the discharge temperature and hence the temperature of the cylinder and piston walls increase with pressure ratio. As the compressor speed increases the heat transfer rate from the compressor to the surroundings reduces, which may result in higher refrigerant temperature. Finally, the type of external cooling provided and compressor design also affects the performance as it influences the temperature of the compressor. Since the compression and expansion processes are accompanied by heat transfer, these processes are not adiabatic in actual compressors. Hence, the index of compression is not isentropic index but a polytrophic index.

However, depending upon the type of the compressor and the amount of external cooling provided, the compression process may approach an adiabatic process (as in centrifugal compressors) or a reversible polytrophic process (as in reciprocating compressors with external cooling). The index of compression may be greater than isentropic index (in case of irreversible adiabatic compression). When the process is not reversible, adiabatic, then the polytrophic index of compression 'n' depends on the process and is not a property of the refrigerant. Also, the polytrophic index of compression may not be equal to the polytrophic index of expansion. Since the compression process in general is irreversible, the actual power input to the compressor will be greater than the ideal compression work. Sometimes the isentropic efficiency is used to estimate the actual work of compression. The isentropic efficiency $\eta_{is}$ for the compressor is defined as:

$$\eta_{is} = \frac{h_{c,is}}{h_{c,act}}$$

Where $h_{c,is}$ is the isentropic work of compression and $h_{c,act}$ is the actual work of compression. It is observed that for a given compressor the isentropic

Efficiency of the compressor is mainly a function of the pressure ratio. Normally the function varies from compressor to compressor, and is obtained by conducting experimental studies on compressors. The actual work of compression and actual power input can be obtained if the isentropic efficiency of the compressor is known as the isentropic work of compression can be calculated from the operating temperatures.

Effect of pressure drops:

In actual reciprocating compressors, pressure drop takes place due to resistance to fluid flow. Pressure drop across the suction valve is called This pressure drop can have adverse effect on compressor performance as the suction pressure at the inlet to the compressor $P_s$ will be lower than the evaporator pressure as shown in Fig.19.11. As a result, the pressure ratio and discharge temperature increases and density of refrigerant decreases. This in turn reduces the volumetric efficiency, refrigerant mass flow rate and increases work of compression. This pressure drop depends on the speed of the compressor and design of the suction valve. The pressure drop increases as piston speed increases.

Even though the pressure drop across the discharge valve is not as critical as the pressure drop across suction valve, it still affects the compressor performance in a negative manner. The net effect of pressure drops across the valves is to reduce the refrigeration capacity of the system and increase power input. The pressure drops also affect the discharge temperature and compressor cooling in an adverse manner.

Effect of leakage:

As a result of the above deviations, the actual volumetric efficiency of refrigerant compressors will be lower than the clearance volumetric efficiency. It is difficult to estimate the actual efficiency from theory alone. Normally empirical equations are developed to estimate this parameter. The actual volumetric efficiency can be defined either in terms of volumetric flow rates or in terms of mass flow rates, i.e.

Actual volumetric efficiency =

$$\frac{\text{actual volumetric flow rate}}{\text{Compressor displacement rate}} \qquad \frac{\text{actual mass flow rate}}{\text{maximum possible mass flow rate}}$$

**Introduction to efficient heat recovery system**

Energy is a basic requirement for the existence and development of human life. Primarily the commercial sources of energy are fossil fuels (coal, oil and natural gas), hydroelectric and nuclear power plants which provide for the energy needs of a country. The fear of release of radioactivity into the atmosphere in the event of an accident or from nuclear waste has forced people to reconsider the use of nuclear power. In view of these problems associated with conventional energy sources, the focus is now shifting to conservation and efficient utilization of energy.

The annual energy consumption of window mounted room air conditioners has increased as those have become a reliable means for providing zoned space cooling of residential and commercial buildings. The new energy efficiency standard for window type air conditioners will take effect in future. Therefore, more energy efficient systems are required to be developed to meet this standard. In order to increase system energy efficiency, component performance is needed to be improved.

It is found that generally the coefficient of performance (C.O.P) of an air conditioner decreases about 2 to 4 % due to increase of each degree Celsius in condenser temperature. So, C.O.P of air conditioner could drop down as much as 40% in hot weather condition. This large reduction of C.O.P means more power consumption for air conditioner in summer when the demand for electric power is high. This increase in power consumption of air conditioner creates more pressure on the power network which is not desirable.

**What is efficient heat recovery System?**

The efficient heat recovery System links two common functions in commercial buildings to increase C. O. P. and achieve cost savings. A refrigeration heat recovery water heating system harvests heat that would normally be rejected to atmosphere through refrigeration condenser system and utilizes this heat for water heating purpose. (E.g. Fig. 1). The primary limitation of refrigeration heat recovery water heating system is the fact that heat is available only when refrigeration system is in operation.

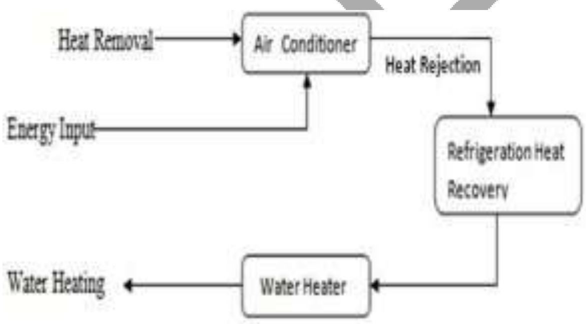


Figure 4.1: Efficient heat recovery system

**4.1. Principle of Refrigeration Heat Recovery System**

Desuperheater is a particular type refrigeration heat recovery system that recovers only the more readily available superheat energy from the host system. They can be either direct or indirect type. In present refrigeration heat recovery system, indirect type of system is used.

**Typical Refrigeration Heat Recovery System implemented**

A refrigeration heat recovery device is indirect type of system in which a refrigerant to water heat exchanger is installed between the host refrigeration system compressor and condenser. Water is circulated through one side of heat exchanger and hot refrigerant gas from the compressor is routed through the other side. Heat is transferred from the hot refrigerant gas to the water.

Most refrigerant heat recovery devices are desuperheaters. Superheat refers to heat stored in the refrigerant vapor when it is heated above the temperature at which it evaporates for a given pressure. Acting as a desuperheater, a heat recovery device cools the refrigerant only to the saturation point. No condensing takes place in the desuperheater. Under typical conditions a desuperheater can remove about 10- 30 % of the total heat that would have been rejected by the condenser.

**DESIGN OF EFFICIENT HEAT RECOVERY SYSTEM**

The heat recovery system is designed for the available desuperheating heat in the window air conditioner. The available heat is calculated by using the rated conditions of the window air conditioner and after that the heat exchanger design is done for that heat recovery.

**A. The Design Process**

The design process will be done based on following guidelines.

1. The heat recovery system will serve as a retrofit for an existing air conditioning unit.
2. It must include provisions for bypassing the heat recovery system. These bypasses must allow normal operations of the air conditioner without heat recovery.
3. The heat recovery system must not require pumps rather it should utilize thermo-siphon effects or tap water.
4. All components of the system should be instrumented with thermometer and manometer.

The material must endure flow and temperature variations and be resistant to corrosion. The heat recovery system components, such as tubes and fittings, must be standardized to lower the cost.

**Technical Details**

AIR CONDITIONER : VOLTAS
MODELNO:MAM541R
SERIALNO.:45111648L015534
POWER SUPPLY: SINGLE PHASE, 230 V, 50 HZ, 13 A.
POWER RATING: 2.5 Kw
REFRIGERANT: R-134A
NORMAL CAPACITY: 1.5 TR AT
COMPRESSOR: HERMITICALLY SEALED ROTARY
CONDENSER: FORCED CONVECTION AIR COOLED
EVAPORATOR: FORCED CONVECTION AIR COOLED
THERMOSTAT: ON PANEL
ENERGY METER: FOR COMPRESSOR PROVIDE
PRESSURE GAUGE: 1 NO. FOR SUCTION PRESSURE AND
1 NO. FOR DISCHARGE PRESSURE
TEMPERATURE INDICATOR: DIGITAL THERMOMETER INDICATOR
AIR FLOW MEASUREMENT: BY INCLINED TUBE MANOMETER

**Methodology**

1. Calculation of energy supplied for refrigeration effect
2. Measurement of heat extracted from cooling space.
3. Design of heat exchanger unit
4Measurement of heat collected in heat exchanger unit.
5. Calculation of COP for normal air conditioning system
6. Calculation of COP for air conditioning system with exhaust heat collection using heat exchanger.
7. Comparison of COP in both above cases.
8. Conclusion

**Technical details**

1. **Calculation of energy supplied for refrigeration effect**

Input power to Air conditioner unit = 2.5 kW = 2500 W = 2500 J / sec

**2. Measurement of heat extracted from cooling space.**

Following observations were taken at evaporator.

**Table 1:** Temperature of Air

| **Temp.of Air** | **DBT $^0$C** | **WBT $^0$C** | **Enthalpy kJ / Kg** |
|---|---|---|---|
| Inlet | 33 | 25 | 77 (H1) |

| | | | |
|---|---|---|---|
| Outlet | 23 | 19 | 54 (H2) |

= 23 kJ/Kg of air flow
Air flow rate = 0.2215 Kg/sec

Hence, heat extracted in evaporator by refrigerant /sec
= 23 * 0.2215 = 5.0945 kJ / sec

= 5094.5 J/sec = 5094.5 W

**Refrigeration Effect**

**Design of Heat Exchanger Unit**

**To find the heat removed from refrigerant during desuperheated conditions:**

Compressor inlet = 4.83 bar
Compressor Outlet = 18.27 bar
Evaporator Temperature = -1$^{O}$C
Condenser Temperature = 47$^{O}$C
Cooling Capacity = 1.5 TR =1.5*3.5= 5.3505kW

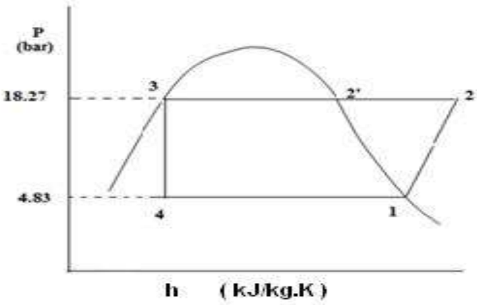


Figure 4.2 Pressure –enthalpy

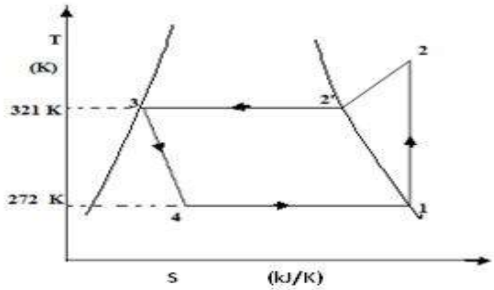


Figure 4.3 Temp.-entropy

To find temp. T2 we have,
S2= S2‘‘ + 2.3 Cp log (T2/T2‘‘) (from 4.3) 1.7521
=1.6893 + 2.3*1.0256 log (T2/320) 1.7521
= 2.3588 log (T2/320)
= 1.7521 – 1.6893 T2
= 68.29OC
Refrigerating effect = h1-hf3 = 404.68 – 259.1 = 145.58 kJ/kg (from 4.2)
Mass flow rate (mR) = 5.3505/145.58 = 0.03675 kg/sec
Heat available for desuperheating (Q)
= mR (h2- h2')
= 0.03675(437.92 – 417.18)
= 0.7651 kW

Q = 765.13 W (i.e. [3])

**RATE OF HEAT EXCHANGE**

GIVEN DATA: -
Inner diameter of tube (Di) = 8.4 mm
Outer diameter of tube (DO) = 10 mm
Thickness of tube (t) = 0.8 mm
Material selected = Copper.
Thermal conductivity (k) = 380 W/m k.
Fouling factor for Refrigerant =0.00017.
Fouling factor for water =0.00017.

- Heat transfer coefficient for refrigerant side hi = 898 W/m$^2$k.
- Heat transfer coefficient for water side ho = 151.58 W/m$^2$k.
- Overall heat transfer coefficient.

1/U =1/hi +1/ho + dx/k + Fr + Fw. =1/898+1/151.48+ 0.8*10$^{-3}$/380+0.00017+0.00017
=1/0.00804
U= 125 W/m$^2$K.

1. To find out Area of Heat Exchanger.
2. Now, outlet temperature of water.

Q= mCp ΔT

765.13 =1/60*4719(T2-30).
T2 = 40.98˚C.
Log mean temperature difference.
=ΔTm. ΔT1=Refrigerant diff.
=69-41=28˚C. ΔT2=Water diff.
=40-30= 10˚C.
ΔTm= ΔT1-ΔT2/ln (ΔT1/ΔT2)
= 28-10/ln (28/10)
ΔTm = 17.49
Now, Area of Heat Exchanger
Q = U*A*ΔTm
A = Q/U*ΔTm
765.13/125*17.49 A = 0.352 $M^2$

**To find Length of Tube.**
A= π*Do*L» L = A/π*D = 0.352/π*10*$10^{-3}$
L= 11.20 Meter. So, L2 = 12 meters

Figure 4.4 Heat exchanger coil

Figure 4.5 Experimental set – up

**Heat extracted by circulating water in heat exchanger:**
Following observations were recorded by running water through heat exchanger. (i.e. Fig.5) Under steady state condition,
**Table 2**: Temperature of Water

| Flow rate of water LPM | Inlet temp. of water $^0$ C | Outlet temp. of water $^0$ C |
|---|---|---|
| 1 | 33 | 43 |

Heat absorbed by water in heat exchanger
Q = m* Cp * ΔT

= 1 * 4179 * (43 – 33) / 60

= 696 W

**5. Analysis of efficient heat recovery system based on co-efficient of performance**
**Calculation of COP for normal air conditioning system COP = Refrigeration** Effect / Input power
= 5094.5 W / 2500 W
= 2.0378
**Calculation of COP for air conditioning system with exhaust heat collection using heat exchanger. COP = (Refrigeration** Effect + heat absorbed by water in heat exchanger) / Input power to Air conditioner unit
= (5094.5 W + 696 W) / 2500 W
= 2.3162
**Comparison of COP in both above cases.**
% increase in COP
= (2.3162 – 2.0378) * 100 /2.0378

= 13.66 %

**CONCLUSIONS**
1. The C.O.P (coefficient of performance) of the system is increased by 13.66% using the heat exchanger with air conditioner.
2. Thermal pollution is reduced.
3. Waste heat is utilized for useful purpose.
4. By regulating water flow rate in heat exchanger, refrigerant can be cooled to required degree.

5. The processes effective recovery of waste heat from the condenser in the refrigeration system by replacing the air condenser with water condenser is more efficient

6. And the obtained hot water is utilized to domestic use and as well as control on industrial application such as RH controls and chemical processes and utilized for all hot water needs for industrial and as well as home applications.

7. The efficiency of condenser increases and hence efficiency of refrigeration cycle increases it indicates efficiency of the air conditioning system increases. Hence the efficiency of the heat recovery system 13% more efficient than general air conditioning system.

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