

# **Experimental Analysis of Waste Heat Recovery System for Combined Refrigerator and Air Conditioning Unit**

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**ABSTRACT:** The objective of this project was to determine the energy savings associated with improved utilization of waste heat from a domestic refrigerator. The continual operation of this equipment accounts more electrical energy consumption. Furthermore, a significant amount of waste heat is rejected by the condensers of refrigerator. The heat rejected by condenser is of low quality, meaning temperature is low. Thus, practical uses of waste heat from the domestic refrigerators are typically limited to space heating and water heating. The system works on basic cooling cycle i.e. Vapour compression refrigeration cycle (VCRS). The system operates on a single compressor and performs both the refrigeration and air conditioning functions. It is an energy efficient system as it offers the triple benefits. This can be used for the commercial as well as domestic purposes. The idea of this project explores the possibility of combining three units i.e. Refrigerator, Air-Conditioner and water heater into a single unit, such that the device saves energy and the lot of space.

**KEYWORDS:** Vapour compression refrigeration cycle, VCRS, triple benefits, possibility of combining three units.

## **I. INTRODUCTION**

The refrigeration cum air-conditioning cum water heater system works on basic cooling cycle - Vapour compression refrigeration cycle (VCRS). The system operates on a single compressor and performs both the refrigeration and air conditioning functions. It is an energy efficient system as it offers the triple benefits. This can be used for the commercial as well as domestic purposes.

The idea of this project explores the possibility of combining three units i.e. Refrigerator, Air-Conditioner and water heater into a single unit, such that the device saves energy and the lot of space. This is how we can try to make the environment and a common man comfortable. This project is about attempt to merge domestic Refrigerator and Air conditioner into a combined system. In metropolitan cities, environment degradation due to automobile & other factors is on the rise, therefore the requirement of air-conditioner has already been felt. The motivation for the project comes from rising energy demands and hence its cost. As we all know that we are lacking of power resources, so this product will help us in tackling this problem as we are trying to make a personalized cooling system which will run at a very low cost that can be afforded by a common man. In minimum construction, maintenance, running cost, this attempt is quite useful for domestic purpose so that our ultimate aim of the project that is those who cannot afford an Air Conditioner can have the comfort of Air Conditioner could be completed. Since all energy cost are on a rise, therefore this project is a way forward in realizing the economic as well as environmental demands. As it is said "the energy saved is the energy produced". On the other hand the common man can have the comfort of Air conditioner. Domestic refrigerator consumes significant amount of energy in buildings like hospitals, hotels, multifamily buildings. By recovering part of energy for air conditioning effect energy can be saved. Since variation of outdoor air temperature is small in tropical countries, cooling is needed year round. This is the best condition to perform combined effect of refrigerator and air conditioners for energy saving. A prototype combined air-conditioning cum refrigeration cum water heater is designed and built.

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Normal refrigerator works on VCRS, extract heat from substance to be cooled and exert that heat to the atmosphere through the device called condenser. That refrigerator which is been previously made to exert a lot of heat through condenser is modified to overcome this wastage of heat. For recovery of that waste heat we decide to develop a machine which utilizes that waste heat for heating water with the use of water heater. The main important thing in our model is, it does not require any kind of additional power supply for its working operation. As the energy saving plays vital role in development, our model has lot of importance from that particular point of view. Another interesting thing in this project is that it performs operation without disturbing original refrigerator working. The refrigerator that we use in our daily routine release lot of heat which goes waste but as per the accessories that attached we have used i.e. Hot water tank used above heat and fullfill the purpose. After the attachment of water heater the efficiency of refrigerator is not affected. The machine fabricated has good utilization in hotels, dairy, industry and also useful for domestic purpose. The serving cooling and heating both the purpose. The wasted heat from condenser utilized for the water heating. This can be used for the commercial as well as domestic purposes. This machine is made by the combination of an air conditioner with refrigerator and water heater System. It can be used in as air conditioner or water heater and a refrigerator. The heat absorbed by the AC can be used in the vaporization of refrigerant and in condenser waste heat eject from the condenser utilised for water heating purpose. It saves a lot of space as 3 machines are combined in a single unit. A unique feature about this is at any time you can switch to start the system. Also it conserves water as the water released by Air Conditioner System can be used for heating water. If you want to drink cool water, you can use the refrigerator box. This is designed for middle class family mainly. For saving energy 1st we can start refrigerator and ac in the room then waste heat from Condenser heat the water.

Waste heat recovery depends upon the various sources of application and temperature range. It broadly classified as given in table1 below,

Sr. No.	Type of heat Recovery	Remark
1	High Temperature Heat Recovery (650-1650°C)	These type of heat recovery results from direct fuel fired processes of industrial process equipment in the high temperature range.
2	Medium Temperature Heat Recovery (230-650°C)	Most of the waste heat in this temperature range comes from the exhaust of directly fired process units in medium temperature range.
3	Low Temperature Heat Recovery (27-230°C)	These type of heat recovery results from bearings, welding machines, injection molding machine, Annealing furnaces, forming dies, Air compressor, pumps, Internal combustion engine, Air conditioning and refrigeration condensers, Drying, baking and curing ovens, Hot processed solid or liquid etc.

A household refrigerator is a common household appliance that consists of a thermally insulated compartment and which when works, transfers heat from the inside of the compartment to its external environment so that the inside of the thermally insulated compartment is cooled to a temperature below the ambient temperature of the room. Tetrafluoroethane (HFC134a) refrigerant was now widely used in most of the domestic refrigerators.

Heat can be recovered by using the water-cooled condenser and the system can work as a waste heat recovery unit. The recovered heat from the condenser can be used for bathing, cleaning, laundry, dish washing etc. Typical waste heat temperature for Air conditioning and refrigeration condensers are 32 to 43°C. Low temperature waste heat may be useful in a supplementary way for preheating purposes. Keeping in mind, a technique for condensing heat of the refrigeration system is proposed in this paper. The proposed system employs a combined air and water-cooling (desuperheating) technique for condensing heat of refrigeration system. This new system provides not only the refrigeration effect, but also hot water.

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## Refrigeration system

Refrigeration system is nothing but the reversed heat engines as the heat engines converts the heat energy into mechanical energy by taking heat from high temperature source and then rejecting to low temperature sink, In contrary to that the refrigeration system consumes some work to transfer heat from low temperature sink to high temperature source. The first mechanically produced cooling system was developed in England in 1834. The process later became known as vapour compression. After invention of electricity automatic refrigeration system was developed in 1897. Basically a refrigeration or air conditioning is nothing more than a heat pump whose job is to remove heat from a lower temperature source and reject heat to high temperature sink. The Vapor Compression Refrigeration Cycle is a process that cools an enclosed space to a temperature lower than the surroundings. To accomplish this, heat should be removed from the enclosed space and dissipated into the surroundings. However, heat tends to flow from an area of high temperature to that of a lower temperature. During the cycle refrigerant circulates continuously through four stages. The first stage is called Evaporation and it is here that refrigerant cools the enclosed space by absorbing heat. Next, during the Compression stage, the pressure of the refrigerant is increased, which raises the temperature above that of the surroundings. As hot refrigerant moves through next stage, Condensation, the natural direction of heat flow allows the release of energy into the surrounding air. Finally, during the Expansion phase, the refrigerant temperature is lowered by what is called the auto refrigeration effect. This cold refrigerant then starts The Evaporation stage again, removing more heat from the enclosed space. Each of the four stages will now be revisited in detail, explaining the physical changes that occur in the refrigerant and the devices used to accomplish these changes.

Refrigeration is the process of removing heat from a substance under controlled conditions. Refrigerator is a reversed heat engine or a heat pump which pumps heat from a cold body and delivers it to a hot body. The substance, which works in a heat pump to extract heat from a cold body and to deliver it to a hot body, is called refrigerant. Refrigeration is accomplished by various methods such as the vapour compression system, absorption system, and steam jet refrigeration cycle. The vapour compression system of refrigeration is widely used.

## Methods of refrigeration

Methods of refrigeration can be classified as *non-cyclic*, *cyclic*, *thermoelectric* and *magnetic*.

### Cyclic refrigeration

This consists of a refrigeration cycle, where heat is extract from a low-temperature space or source and rejected to a high-temperature sink with the help of external work, and its inverse, the thermodynamic power cycle. In the power cycle, heat is supplied from a high-temperature source to the engine, part of the heat being used to produce work and the rest being rejected to a low-temperature sink. This satisfies the second law of thermodynamics.

A *refrigeration cycle* describes the changes that take place in the refrigerant as it alternately absorbs and rejects heat as it circulates through a refrigerator. It is also applied to heating, ventilation, and air conditioning HVACR work, when describing the "process" of refrigerant flow through an HVACR unit, whether it is a packaged or split system.

Heat naturally flows from hot to cold. Work is applied to cool a living space and storage volume by pumping heat from a lower temperature heat source into a higher temperature heat sink. Insulation is used to reduce the work and energy needed to achieve and maintain a lower temperature in the cooled space. The working principle of the refrigeration cycle was described mathematically by Carnot in 1824 as a heat engine.

The most common types of refrigeration systems use the reverse-Rankine vapor-compression refrigeration cycle, although absorption heat pumps are used in a minority of applications.

Cyclic refrigeration can be classified as:

1. Vapor cycle, and
2. Gas cycle

Vapor cycle refrigeration can be classified as:

1. Vapor-compression refrigeration
2. Vapor-absorption refrigeration

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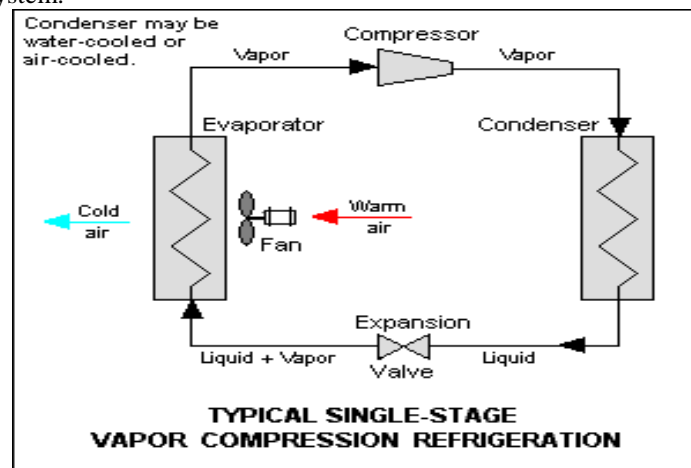
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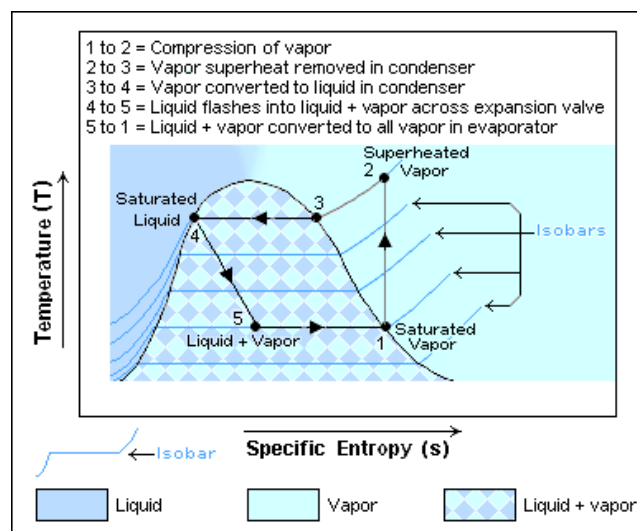
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## Vapor-Compression Refrigeration Cycle

The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Figure 1 provides a schematic diagram of the components of a typical vapor-compression refrigeration system.



The thermodynamics of the cycle can be analyzed on a diagram as shown in Figure. In this cycle, a circulating refrigerant such as Freon enters the compressor as a vapor. From point 1 to point 2, the vapor is compressed at constant entropy and exits the compressor as a vapor at a higher temperature, but still below the vapor pressure at that temperature. From point 2 to point 3 and on to point 4, the vapor travels through the condenser which cools the vapor until it starts condensing, and then condenses the vapor into a liquid by removing additional heat at constant pressure and temperature. Between points 4 and 5, liquid refrigerant goes through the expansion valve (also called a throttle valve) where its pressure abruptly decreases, causing flash evaporation and auto-refrigeration of, typically, less than half of the liquid.



That results in a mixture of liquid and vapor at a lower temperature and pressure as shown at point 5. The cold liquid-vapor mixture then goes through the evaporator coil or tubes and is completely vaporized by cooling the warm air (from the space being refrigerated) being blown by a fan across the evaporator coil or tubes. The resulting refrigerant vapor returns to the compressor inlet at point 1 to complete the thermodynamic cycle.

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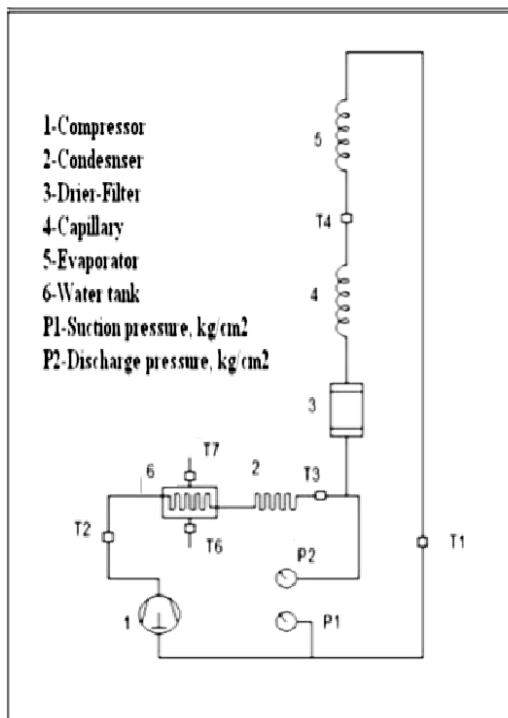
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The above discussion is based on ideal vapor-compression refrigeration cycle, and does not take into account real-world effects like frictional pressure drop in the system, slight thermodynamic irreversibility during the compression of the refrigerant vapor, or non-ideal gas behavior.

## II. RELATED WORK

### Experimental Set up



Experimental setup consists of 200 L capacity, single door LG refrigerator. The system was retrofitted with a water tank having capacity of 2 L. The refrigerator is having a vertical cabinet. A tank made-up of MS is fitted at the beginning of the condenser line. A portion of the condenser line is immersed in the tank for DE superheating of refrigerating gas. The volume of water used for testing is 2L. A water in tank was kept stationery till water get temperature more than 40°C. An instrument panel made-up of MS is used for mounting gauges. Pressure gauges indicating suction pressure of compressor and pressure after condensation. Also an energy-meter has been used to measure the energy consumption. A temperature sensor set has been used to monitor various temperatures encountered in the system.

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Symbol	Component	Symbol	Component
T1	Temperature after evaporation	T6	Water inlet temperature
T2	Temperature after compression	T7	Water outlet temperature
T3	Temperature after condensation	P1	Suction pressure of compressor
T4	Temperature after throttling	P2	Pressure after condensation

## Specifications of Experimental Set-up

Following are the specifications of the various components of experimental setup used.

- Condenser-M S coil, Inner dia. 3mm, Outer dia. 5mm, Length 4.5m
- Tank-M S sheet, Gauge 24, Size 120mm x 105mm x 280mm
- Hermetically sealed compressor- Model THK1340YCF, Min. Pressure 8psi, Max. Pressure 140psi
- Refrigerant-R134a
- Evaporator
- Axial fan-230Volt
- Digital Thermometer-Model PM10, Range -50 to 100°C
- Pressure Gauges- Suction pressure gauge- 'BABA' make, Range 0 to 250psi,  
Discharge pressure gauge- 'SYNERGY' make, Range 0 to 500psi
- Energy Meter- 240V, 5-30A, CL1, 50Hz, 3200imp/kWhr

## Experimental Procedure

- After the installation of the components on refrigerator test setup started. Test was conducted in two phases which are as follows-  
No Load (Refrigerator door fully closed), with and without water  
Full Load (Refrigerator door fully opened), with and without water
- At each load conditions temperature and pressure at salient points were noted down at every thirty minutes interval.
- The initial and final temperature of the water also measured. The test were conducted until steady state is reached.
- To find out energy consumption energy meter reading were noted.
- For finding out the coefficient of performance compressor suction and discharge pressure were used. Once equilibrium temperature were reached between water and condensing temperature it was found that, there is no more change in temperature of water. The water temperature was upto satisfactory level or preheated state. Once water got preheated state the water tank filled fresh water and procedure repeated.

## Specimen Calculation

Density of water = 1000 kg/m<sup>3</sup>

Specific heat of water,  $C_{pw} = 4.18 \text{ kJ/kg-K}$

Specific heat of refrigerant,  $C_{pr} = 1.51 \text{ kJ/kg-K}$

Volume of water,  $V = 2 \text{ ltr} = 0.0002 \text{ m}^3$

All temperatures in degree C and pressures in kg/cm<sup>2</sup>

For finding out the COP of the system, the enthalpies at all the points of the cycle are calculated.

So for that first find the dryness fraction (x) at pt. 1, We know that entropy at pt. 1,

$S_1 = sf_1 + x hfg_1/T_1$  and  $S_2 = sf_2 + x hfg_2/T_2$

But  $S_1 = S_2$



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So,  $sf_1 + x hfg_1/T_1 = sf_2 + hfg_2/T_2$

1) The refrigerating effect is calculated as,

$$Re = h_1 - h_4, \text{ kJ/kg}$$

2) The work done per kg of refrigerant is given by,

$$W = h_2 - h_1, \text{ kJ/kg}$$

3) The coefficient of performance is given by,

$$COP = (Re/W) = (h_1 - h_4 / h_2 - h_1)$$

4) The coefficient of performance using Carnot cycle is given as,

$$COP (\text{Carnot}) = (T_e / T_c - T_e)$$

5) Also, Heat gained by evaporator,  $Q_e = h_1 - h_4, \text{ kJ/kg}$

Heat rejected by condenser,  $Q_c = h_2 - h_3, \text{ kJ/kg}$

6) Now, to calculate heat gained by water

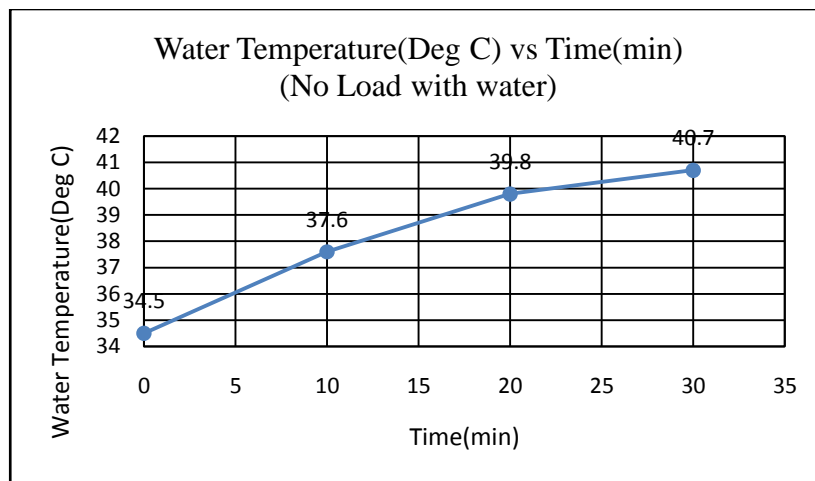
$$Q_w = (m_w * C_{p_w} * T), \text{ kJ/kg}$$

7) The power consumption is calculated as,

$$P = (\text{energy meter reading}) * 3600, \text{ kW}$$

## III. EXPERIMENTAL RESULTS

### Temperature Vs Time (No load with water)



**Graph 1:-** Temperature Vs Time (No load with water)

The Graph 1 shows the variation of water outlet temperature with respect to time (minutes) at no load condition with water. From the Graph 1, it is cleared that the water outlet temperature increases linearly as the time proceeds. The total water outlet temperature rise is observed to be 6.2°C in the time duration of 30 minutes.

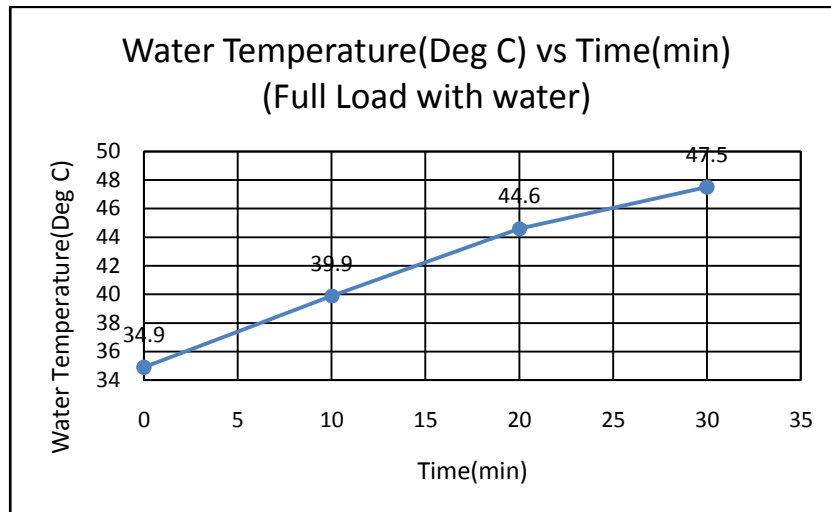
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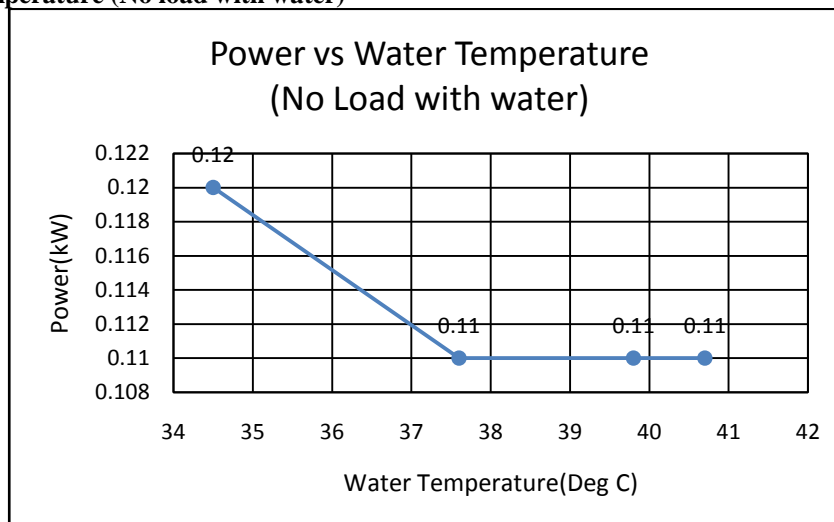
### Temperature Vs Time (Full load with water)



**Graph 2:-** Temperature Vs Time (Full load with water)

The Graph 2 shows the variation of water outlet temperature with respect to time (minutes) at full load condition with water. From the Graph 2, it is cleared that the water outlet temperature increases linearly as the time proceeds. The total water outlet temperature rise is observed to be  $12.6^{\circ}\text{C}$  in the time duration of 30 minutes.

### Power Vs water temperature (No load with water)



**Graph 3:-** Power Vs water temperature (No load with water)

The Graph 3 shows the variation of power with respect to water outlet temperature at no load condition with water. From the Graph 3, it is cleared that the power consumption reduces as water outlet temperature increases with time. At the start of the process power consumption is 0.12 kW and then it reduces rapidly to 0.11 kW and then it becomes nearly constant for the remaining time.



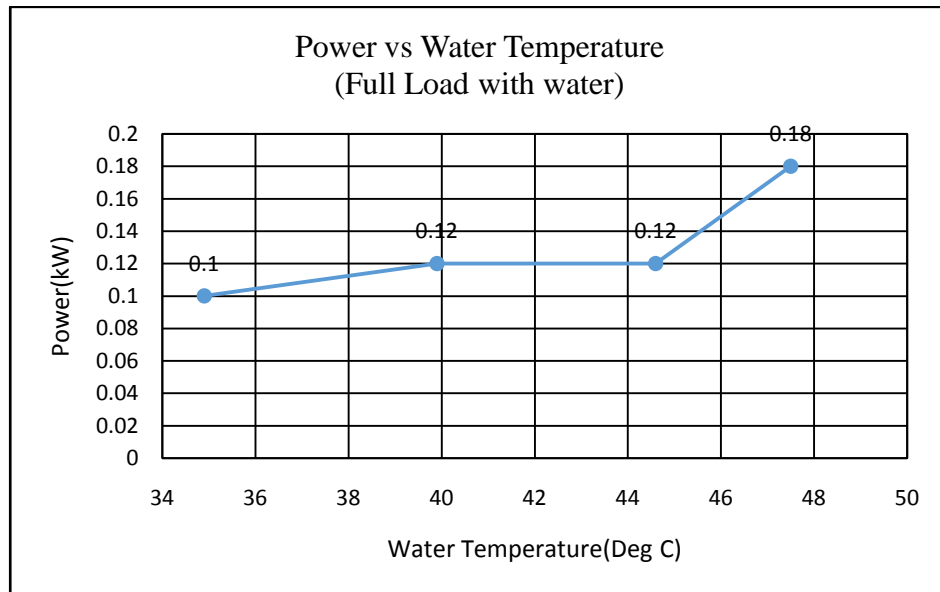
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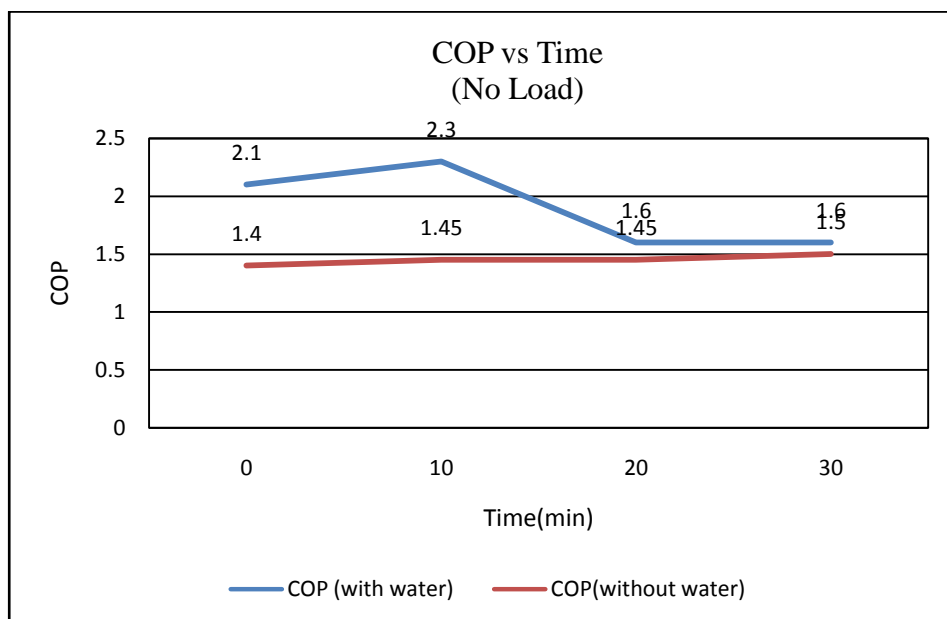
## Power Vs water temperature (Full load with water)



**Graph 4:-** Power Vs water temperature (Full load with water)

The Graph 4 shows the variation of power with respect to water outlet temperature at full load condition with water. From the Graph 4, it is cleared that the power consumption increases as water outlet temperature increases with time.

## COP Vs Time (No load with and without water)



**Graph 5:-** COP Vs Time (No load with and without water)

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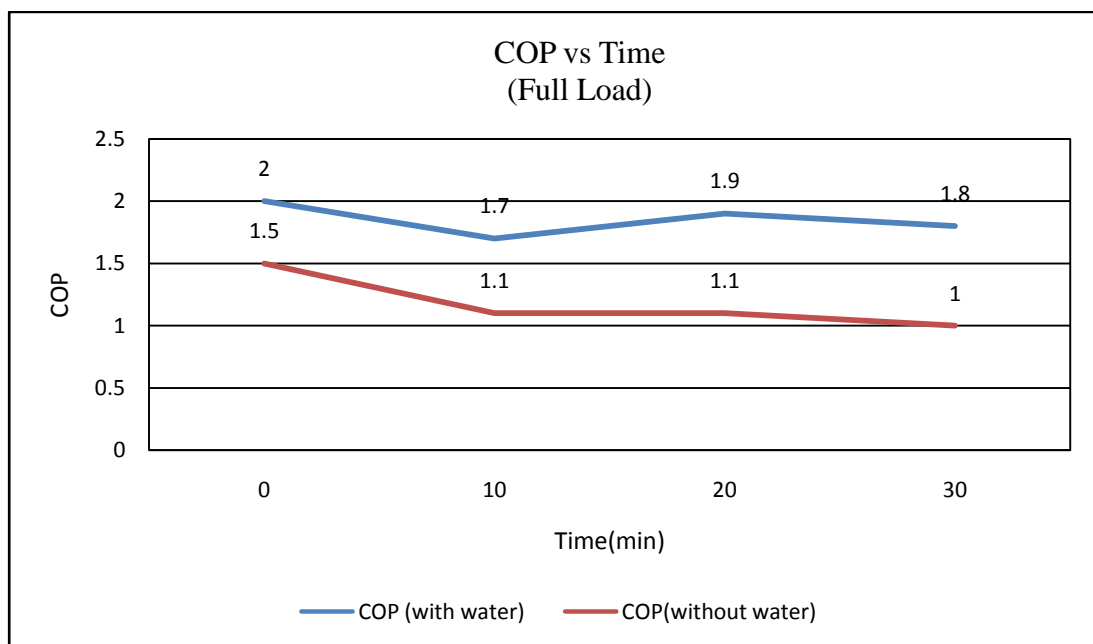
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The Graph 5 shows the variation of COP with respect to time (minutes) at no load condition with water and without water. From the Graph 5, it is seen that the COP of the system without water is almost nearly constant throughout the time. COP of the system with water initially increases and then decreases with small amount and then after sometimes its achieved constant value. Also it is observed that the COP of system with water is higher than the COP of the system without water.

## COP Vs Time (Full load with and without water)



**Graph 6:-** COP Vs Time (Full load with and without water)

The Graph 6 shows the variation of COP with respect to time (minutes) at full load condition with water and without water. From the Graph 6, it is seen that the COP of the system without water is decreases slightly and then almost remains constant throughout the time. COP of the system with water initially decreases and then increases. Also it is observed that the COP of system with water is higher than the COP of the system without water.

## IV. CONCLUSION

It can be concluded that the system while operating under full load condition gives a better COP as compared to no load condition. Hence if the system continuously operates under full load, the COP can be increased. The heat absorbed by water has been observed to be maximum during full load. The heat recovery technique, which can be applied to a refrigeration system provides a compound air-cooling and water-cooling. The use of heat recovery system illustrates the improvement in COP and the reduction in power consumption. The temperature difference obtained between the water inlet and outlet exceeds 10°C. Thus a more optimum and efficient system can be built to give better results. The heat recovery module can be used in various refrigeration applications as well as in air conditioning.

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