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Performance Analysis of Packaged Air-Conditioner

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ABSTRACT–

In the refrigeration system, basically three components are used: condenser, compressor, and evaporator. In that the evaporator is modified by using fins in order to increase the heat transfer rate. Air-conditioning contributes significantly to high energy consumption in commercial buildings. It is essential to monitor and evaluate the performance of air conditioning systems to avoid unnecessary energy wastage.

Present work is refrigeration system analysis and the performance of air conditioner for various room temperatures and the performance analysis of evaporator. In this work, the evaporator is attached with fins to enhance the heat transfer rate by increasing the surface area. The temperature is recorded every 15 minutes for R22 refrigerant. The COP is calculated to evaluate the refrigeration effect. Bypass factor is calculated at various mass flow rate of air for performance analysis of evaporator.

The results of the air-conditioning system's performance and thermal comfort analysis are presented and a comparison is made at various load conditions. Although the results indicate a satisfactory coefficient of performance for the building despite the age of the system, recommendations on system improvements are proposed to further save energy.

Keywords –Air conditioning, fin-tube evaporator, room temperature, bypass factor, overall heat transfer coefficient.

Introduction –

Air conditioning is the process of removing heat and controlling the humidity of air in an enclosed space to achieve a more comfortable interior environment by use of powered "air conditioners" or a variety of other methods, including passive cooling and ventilative cooling. Air conditioning is a member of a family of systems and techniques that provide heating, ventilation, and air conditioning (HVAC). According to the International Energy Agency (IEA), as of 2018, 1.6 billion air conditioning units were installed, which accounted for an estimated 20% of electricity usage in buildings globally with the number expected to grow to 5.6 billion by 2050.

In order to implement energy saving initiatives, the performance of the air-conditioning systemshould be a major consideration. The performance of an air-conditioning system is measured by the Coefficient of Performance or COP. It is the ratio of the desired output over the required input of the system which is a ratio of the heat removed from the cooled space over the input work or electricalenergy consumed. Thermal comfort is also an important consideration in evaluating theperformance of an air-conditioning system. The main factors that affect thermal comfort are dry bulb temperature, relative humidity and air velocity.

Various parameters such as COP, compressor work done, and the effect of refrigerant have been studied. It has been inferred that the effect of refrigeration and COP shall be increased by increasing the evaporation temperature and condensation temperature. It is also been inferred that the work done reduces with the increasing evaporation temperature.

Literature Review-

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Experimental Setup -

Description of the test apparatus

Air-conditioning systemis developed considering variable indoor (artificial chamber) and outdoor (suction chamber) design conditions. The variable conditions are achieved with the help of heater and humidifier. This system consists of different apparatus to perform different functions.

Process Blower: This is induced draft blower fitted after the evaporator for transferring the cooled air to the artificial room, where indoor conditions are maintained with the help of heater and humidifier.

Regeneration Blower: The regeneration blower is fitted in between condenser and desiccant wheel, which takes hot air from condenser and made to flow through upper portion of desiccant wheel for desorption process.

Dampers: - Total 2 Dampers are installed to control the mass flow rate of air at various location as per requirement.

Ducts: - There are 3 ducts are present this test ring for various purpose at various locations - Suction duct, return duct, flexible duct.

CoolingCoil: - This is a conventional cooling coil it also known as evaporator. The conventional cooling coil is situated at suction duct, which has Cooling capacity 2TR.

Condenser: This is also conventional condenser coil. It is situated in the return duct which is before the suction side of the regeneration blower. After onwards the hot air from the condenser is used as a heat source for regeneration air.

HeatingCoils: Heating coils are installed at suction, artificial chamber and after condenser for generating required conditions as per requirements.

ArtificialChamber: This chamber is used for producing the indoor load conditions as per the requirement

ControlPanel: It consist of energy meters to monitor the actual accurate energy consumptions of different equipment's so that we get exact power consumption of the system.

MeasuringInstruments: The various measurements are taken in this system such as, Temperature,pressure drops, velocity, relative humidity with the help of high accuracy instruments.

Data Reduction –

1. Refrigeration System Analysis

Cooling Capacity,

$$Q_L = \dot{m}_a(h1 - h2) \ldots\ldots \quad (1.1)$$

where,

$$\dot{m}_a = \rho .\ A_{c/s} .\ V \ldots\ldots \quad (1.2)$$

$h1 and\ h2$ values are taken from psychrometric chart.

Work Input,

$$W = W_C + W_B$$

Coefficient of performance, COP can be calculated as follows;

Actual COP,

$$COP_{act} = \frac{Q_L}{W} \ldots\ldots \quad (1.3)$$

Theoretical COP,

$$COP_{th} = \frac{(h1 - h4)}{(h2 - h1)} \ldots\ldots \quad (1.4)$$

Relative COP,

$$COP_{rel} = \frac{COP_{act}}{COP_{th}} \ldots\ldots \quad (1.5)$$

2. Performance of Air-Conditioner for Various Room Temperature

Cooling Capacity, $Q_L = \dot{m}_a (h1 - h2)$ ……………………………… (2.1)

where,

$\dot{m}_a = \rho.\ A_{c/s}.\ V$ ……………………………… (2.2)

$h1$ and $h2$ values are taken from psychrometric chart.

Work Input,

$$\dot{W} = \dot{W}_C + \dot{W}_B$$

Coefficient of performance, COP can be calculated as follows;

Actual COP,

$$COP_{act} = \frac{Q_L}{W} \text{ ……………………………… (2.3)}$$

Theoretical COP,

$$COP_{th} = \frac{(h1-h4)}{(h2-h1)} \text{ ……………………………… (2.4)}$$

Relative COP,

$$COP_{rel} = \frac{COP_{act}}{COP_{th}} \text{ ……………………………… (2.5)}$$

2.1 Annual Cost-

Annual Cost = Unit Consumption per Hour × 8 hrs ×7 Rs per unit× 30 days ×12 months……………………………… (2.1.1)

3. Performance Analysis of Evaporator

Bypass factor for various load conditions,

$$BPF = \frac{T_{d2} - T_{d3}}{T_{d1} - T_{d3}} \text{ ……………………………… (3.1)}$$

Overall Heat transfer coefficient,

$Q = UA\ LMTD = m\ C_p\ (T_{d1} - T_{d2})$ ……………………………… (3.2)

Where,

$$LMTD = \frac{\theta_1 - \theta_2}{\ln(\frac{\theta_1}{\theta_2})} \text{ ……………………………… (3.3)}$$

Results and Observations -

1. Refrigeration System Analysis

Load Conditions	T (°C)	R_H (%)	P_s (bar)	P_d (bar)	h (KJ/kg)	Q_L (KW)	W (KW)	COP_{act}	COPth
Initial	20.1	52.8	1.51	11.72	41.79	---	---	---	---
33%	30.9	30.4	2.06	12.75	48.85	2.012	0.39	5.15	6.5
66%	31.5	28.3	2.34	12.75	47.18	1.53	0.36	4.42	5.13
100%	31.8	28.1	2.41	12.41	46.72	1.40	0.35	4.0	4.95

2. Performance of Air-Conditioner for Various Room Temperature

Load Conditions	Without Evaporator			With Evaporator			W (KW)	Q_L (KW)	COP_{act}	COP_{th}
	T (°C)	R_H (%)	h (KJ/kg)	T (°C)	R_H (%)	h (KJ/kg)				
Initial	32.6	28.2	54.93	11.4	73.0	26.85	0.563	2.24	4.50	5.08
33%	46.6	15.7	73.28	17.6	58.9	36.36	0.513	2.95	5.90	6.34
66%	49.5	11.4	73.43	19.0	56.2	38.59	0.450	2.78	6.19	6.96
100%	51.9	9.9	73.92	20.2	55.5	41.07	0.400	2.62	6.57	7.31

3.Performance Analysis of Evaporator

3.1 Bypass Factor Calculations (@1250 rpm)

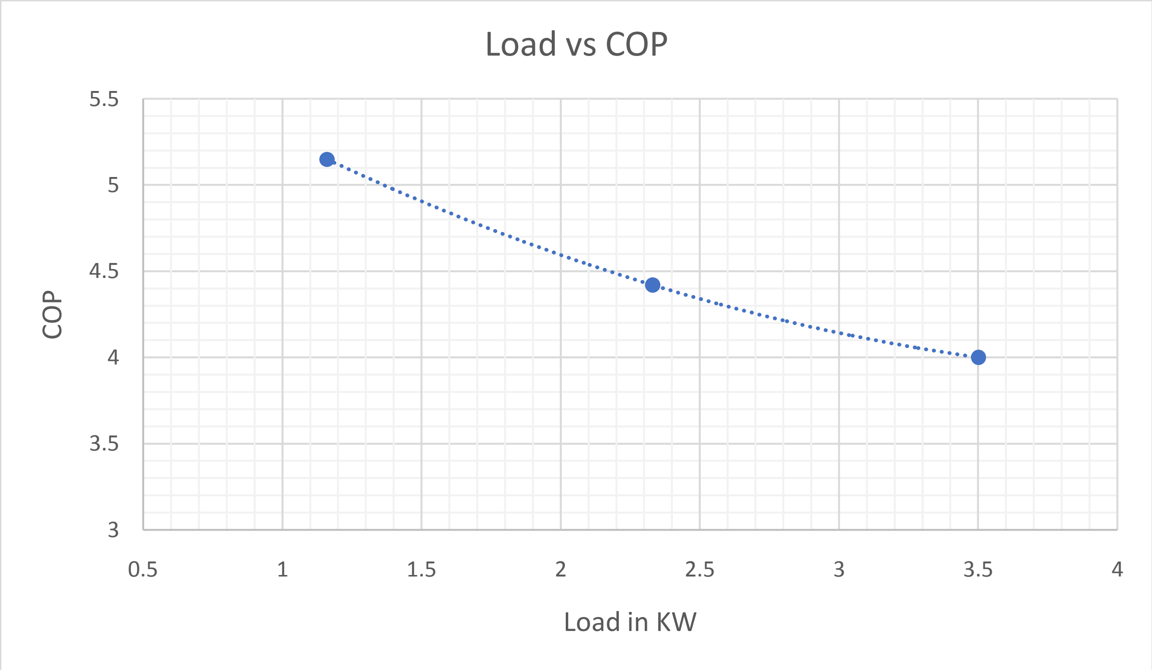
Load Conditions	T_{d1} (°C)	R_{H1} (%)	T_{d2} (°C)	R_{H2} (%)	T_{d3} (°C)	BPF
Initial	33.5	21.60	9.2	71.5	2.7	0.211
25%	33.5	21.60	15.2	61.4	8.0	0.282
50%	33.5	21.60	15.6	60.2	8.7	0.298
75%	33.5	21.60	14.9	60.2	7.0	0.498
100%	33.5	21.60	15.1	59.2	7.2	0.524

3.2 Overall heat transfer coefficient calculation (@ 1500 rpm)

Load Conditions	T_{d1} (°C)	R_{H1} (%)	T_{d2} (°C)	R_{H2} (%)	T_{d3} (°C)	BPF	LMTD (°C)	Q_L (KW)	UA (W/°C)
Initial	34.9	22.0	11.7	74.2	6.0	0.19	15.154	9.872	635.26
25%	35.0	22.4	15.0	63.1	7.2	0.281			
50%	35.6	22.7	15.6	61.7	7.8	0.287			
75%	35.7	22.6	15.9	61.7	8.8	0.272			
100%	35.9	23.1	16.0	61.8	8.9	0.275			
Avg.	35.42		14.84		7.72				

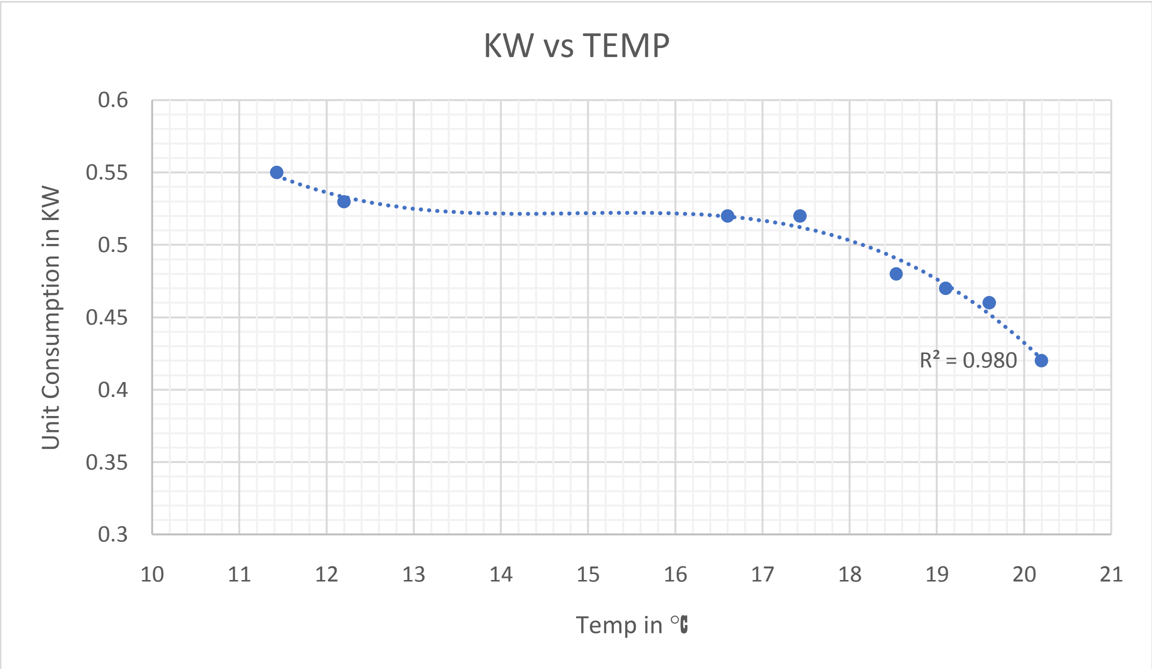
Conclusions-

Partial load tests conducted for RAC showed that as the load decreased, the COP increased and the highest COP was obtained at around 30%–50% load; as the load decreased further, the COP decreased.

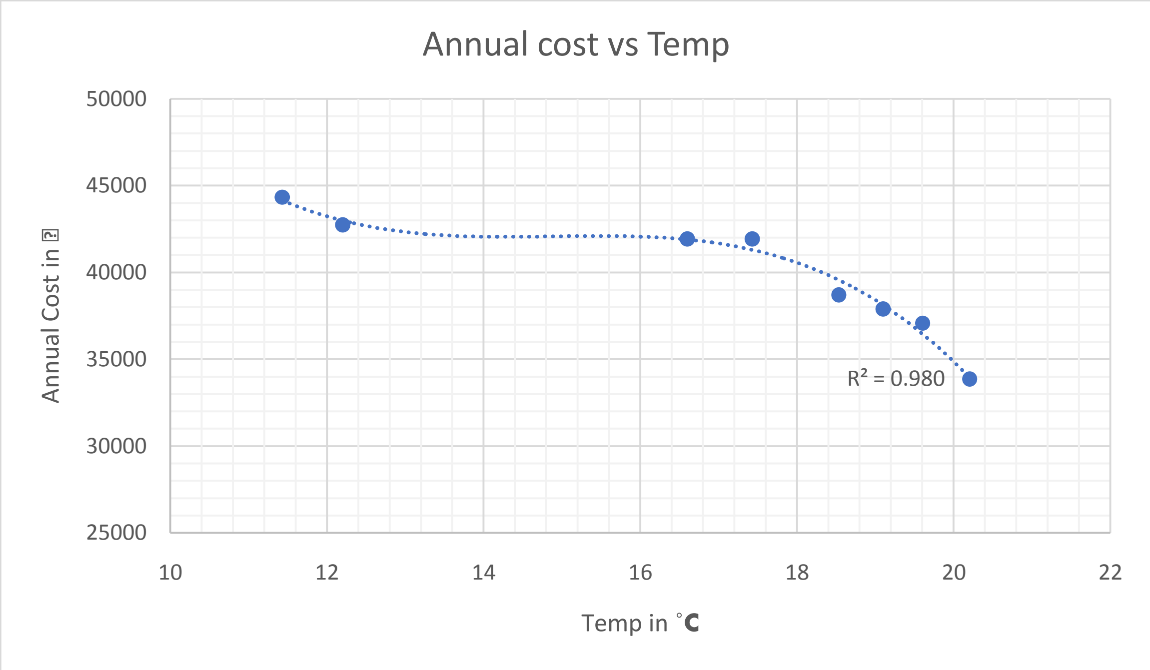


The test is conducted to investigate effect of load on COP of system. The actual andtheoretical COP is calculated by using equation no. 1.3 and 1.4 resp. in data reduction, it is found that the COP is decreases as the load in the system increases. This is due to increase in evaporating temperature.

From the following chart we can conclude that it takes more energy consumptionfor maintaining low room temperature.

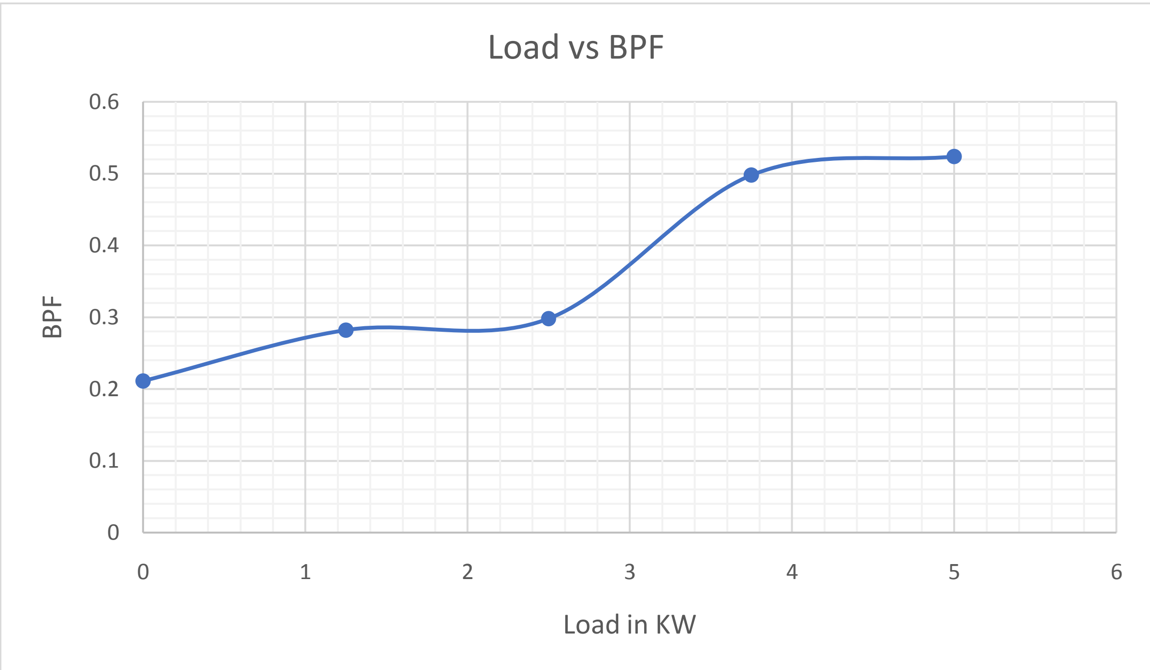


The test is conducted to investigate effect of room temperature on energyconsumption of system. It is found that energy consumptiondecreases with increase in room temperature.



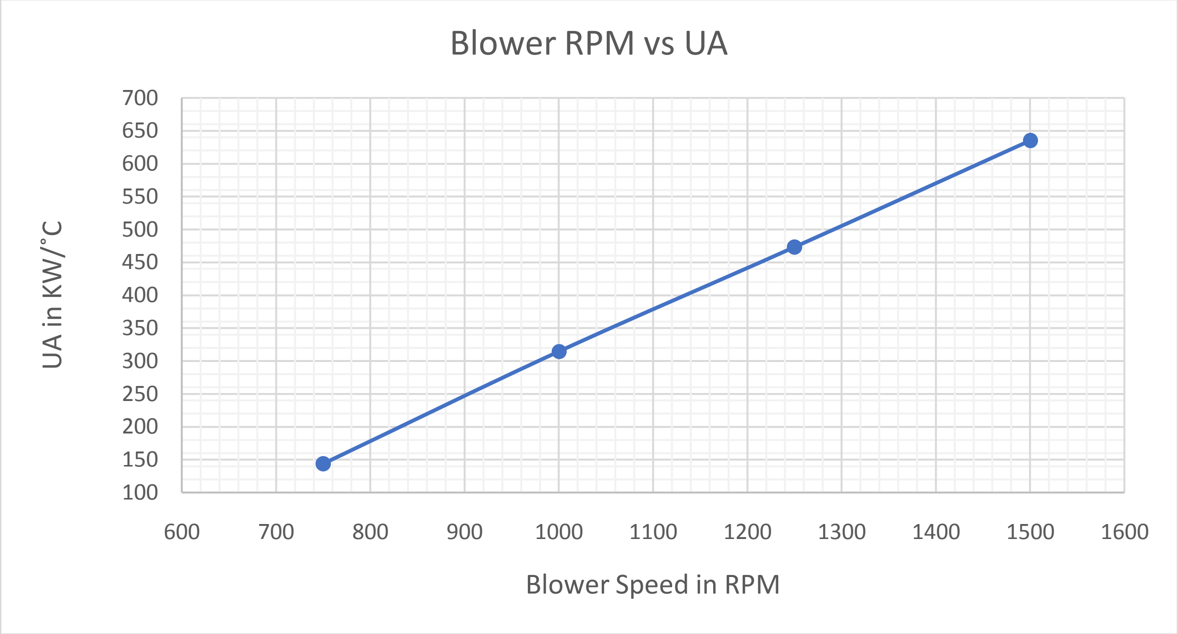
The test is conducted to investigate effect of room temperature on energy cost of system. The annual cost is obtained as per equation no. 2.1.1 in data reduction it is found that energy consumption and consequently the energy cost decreases with increase in room temperature. This is due to increase in evaporating temperature. It is seen from the graph that the annual cost near by remain same for temperature range 11˚C to 17 ˚C and it decreases drastically from 17˚C to 21˚C. Hence we can conclude that for economical working and power saving the temperature should be maintained in range 17˚C to 21˚C.

From table no. 3.1, we can conclude that as the load increases the bypass factor also increases.



The test is conducted to investigate effect of load on bypass factor of system. The bypass factor is calculated by equation no. 3.1 in data reduction, it is found that the bypass factor is increases with increase in load in system. It is seen from the graph that bypass factor drastically increases from 2.5 KW and is maximum at 5 KW load.

From table no. 3.2, we can conclude that as the load increases overall heat transfer coefficient also increases.



The test is conducted to investigate effect of blower speed on overall heat transfer coefficient (UA) of system. The overall heat transfer coefficient is calculated by equation no. 3.2 and 3.3 in data reduction, it is found that the overall heat transfer coefficient increases with increase in blower speed. This is due to increase in mass flow rate.

Nomenclature –

ρ Density of the fluid
Ac/s Cross sectional Area of duct
V Velocity of air
$\dot{m}\ a$ Mass flow rate
hi Indoor enthalpy
$h1$ Enthalpy at inlet of Evaporator.
$h2$ Enthalpy at Outlet of Evaporator.
$h3$ Enthalpy at Outlet of Evaporator when desiccant wheel is ON.
$\dot{Q}_L$ Cooling capacity
$\dot{W}$ Total Work Input
W_C Work input by Compressor
W_B Work input by air blower
TR Tons of Refrigeration
AHU Air Handling Unit
COP Coefficient of performance
kW/TR Specific power consumption of the system