# Thermodynamics Evalution of the Effect of Ambient Temperature in the Performance of Airconditioning System in the Temperate Region

KINGSLEY E. MADU[1], CHIKE M. ATAH[2]

[1, 2] *Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State.*

***Abstract- The thermodynamic evaluation of the effect of ambient temperature in the performance of an air conditioning system in a temperate region was carried out. A 20 ton capacity air conditioner was designed and used for the experiment. Thermodynamics analysis of the system was carried out using the PH and TS diagram. The coefficient of performance (COP) was calculated to be 2.02. The effect of the ambient temperature on the enthalpy value after compression, the COP and the exergy of the system designed was studied. The enthalpy and the exergy of the system were seen to be increasing with increase in ambient temperature. While the COP decreased as the ambient temperature increases. The work done on the compressor was gotten as 34.85 J.***

***Indexed Terms- Ambient Temperature, Temperate Region, Air Conditioning, COP, Thermodynamics***

## I. INTRODUCTION

Air-conditioning is the control of temperature, humidity, purity, and motion of air in an enclosed space, independent of outside conditions.(Wu J et al 2012). The science and practice of creating a controlled climate in indoor spaces is called air-conditioning. Man lives in all the parts of the world-from Antarctica to the African deserts. Only in a very few favored areas of the earth's temperate zone can people live and work comfortably round the year without any air conditioning. From the earliest times, artificial cooling has been recognized as desirable. In every era people have invented primitive methods for cooling strictly as a luxury rather than as a necessity-snow, ice, and cold water when available were used for small-scale cooling. Atmospheric evaporation of water was also used crudely without much understanding of the underlying principles. The primitive method of heating for comfort, was building open fires in caves and tents. Fireplaces in medieval Europe were hardly an improvement. Ancient Romans circulated warm air in hollow floors or walls to provide radiant heating. This was an improvement over the localized radiation from a fireplace. Around 2500 BC, the method of ice making by radiative cooling by sky at night time from water kept in shallow earthen pots was popular in dry climates in India, Egypt, and China. Until the 20th century, Americans dealt with the hot weather as many still do around the world: They sweated and fanned themselves. Primitive air-conditioning systems have existed since ancient times, but in most cases, these were so costly and inefficient as to preclude their use by any but the wealthiest people. In the United States, things began to change in the early 1900s, when the first electric fans appeared in homes. But cooling units have only spread beyond American borders in the last couple of decades, with the confluence of a rising global middle class and breakthroughs in energy-efficient technology. Attempts to control indoor temperatures began in ancient Rome, where wealthy citizens took advantage of the remarkable aqueduct system to circulate cool water through the walls of their homes. The emperor Elagabalus took things a step further in the third century, building a mountain of snow—imported from the mountains via donkey trains— in the garden next to his villa to keep cool during the summer. Marvelously inefficient, the effort presaged the spare-no-cost attitude behind our modern-day central

### 1.1 Air Conditioning System

An air conditioning system, including a condenser for condensing a refrigerant, a first expansion device for throttling the refrigerant passed through the condenser, a second expansion device for throttling the refrigerant passed through the first expansion device, an evaporator for evaporating the refrigerant passed through the second expansion device, a compressor for compressing the refrigerant passed through the evaporator and the refrigerant injected after branched between the first expansion device and the second expansion device, and a control unit for detecting a value of at least one operating parameter and determining a target opening degree of the first expansion device on the basis of a stored set value corresponding to the detected value of the operating parameter. (kim D.H et al 2014).

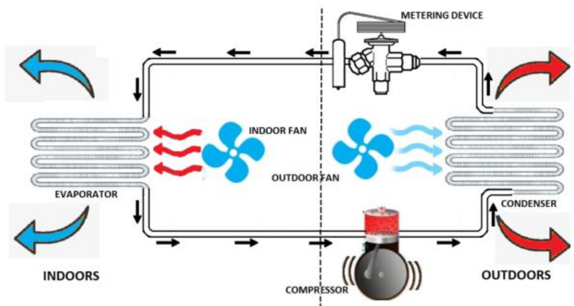


Figure 1 An air conditioning system.

Temperate climates of the Earth are characterized by relatively moderate mean annual temperatures, with average monthly temperatures above 10°C in their warmest months and above −3°C in their colder months (Paula Pratolongo, Andrew plater 2019). Most regions with a temperate climate present four seasons, and temperatures can change greatly between summer and winter.Most people live in temperate zones, and human population densities in coastal regions are about three times higher than the global average (Paula Pratolongo, Andrew plater 2019). Globally, nearly all temperate coastal regions experienced net immigration during the last century (Neumann et al., 2015), and the increasing population associated with rapid economic growth (Hugo, 2011; Smith, 2011) has led to extensive conversion of natural coastal wetlands to agriculture, aquaculture, and silviculture, as well as industrial and residential uses .

Humans both influence and depend on the extensive ecosystem services that temperate coastal wetlands provide, sustained by biological populations and their dynamic interaction with physical and chemical properties of the environment (Kirwan and Megonigal, 2013). The interaction of biota, hydrology, and sediments is clearly evident in the ecological and geomorphologic characteristics of temperate coastal wetlands. Living organisms respond to abiotic factors such as tidal inundation, climate, groundwater, accommodation space (the space between sediment surface and mean sea level), and sediment dynamics, as well as human interventions. The pale environmental records preserved in coastal wetlands provide both ecological and chronological information on their evolution in response to many of these factors and reveal valuable information concerning past climate change, vegetation history, pale hydrology, sea level trends, and alteration by human activities (.Corberán, J.-M. et al 2011)

The capacity of an air conditioner depends upon:

- Climate.
- Outdoor humidity.
- Room size.
- Ceiling height.
- The construction material of home.
- Floor level.
- Number of people in the house.

(Ahmad Sharifian1, Jeri Tangalajuk Siang 2022).

Higher ambient temperatures reduce the cooling capacity of air conditioning systems. Efficient insulation and proper airflow management help mitigate the impact of ambient temperature on air co Air conditioning system (Mohd Hazwan Yusof et al 2018).. This work shall focus on the effect of ambient temperature on the performance of an air conditioning system.

Thermodynamic analysis can formulate the various performance criteria such as thermal equilibria, balance equations, kinetic relations and equations of state. Optimization seeks the best solution under specific constraints. Some methods are the linear and nonlinear programming, dynamic programming, and maximum principle. The complexity of the optimization problem depends on the complexity of the constraints, which may be in algebraic, difference, differential, and integral forms. For the static optimization problems the constraints are algebraic, for variational problems or dynamic optimization the constraints are differential equations.

We may use the second law analysis and exergy analysis to evaluate the systems. The second law analysis is based on the determination of entropy generation due to the irreversibilities in the system. The analysis can determine whether an existing design is thermodynamically sound or not for a certain operating condition. By modifying the operating conditions, sometimes, it would be desirable to minimize or to distribute the entropy generation evenly along the space and/or time variables in the system to attain a thermodynamic optimum. The entropy generation distribution ratios are especially useful in exhibiting the tradeoff between the sources of irreversibilities within the system.

Exergy analysis determines quantitatively the deviation from a reference (dead) state; it shows the level of irreversibility of the processes considered or the exergy destruction in the system. Most of the thermal systems have the exergy inputs resulting from the consumption of fossil fuel, and losses of exergy are related to the waste of these resources. The exergy balance can help to identify the locations, types and magnitudes of energy resource waste, and hence to develop designs for more efficient use of resources (Takdanai Suparos et al 2022). Based on the exergy destruction we may decide whether the modifications in the process will lead significant energy saving. Exergy analysis completes energy analysis towards obtaining optimal design or optimal operation in the thermodynamic sense. Exegetic efficiencies can be used to evaluate the performance by comparing the efficiencies before and after the modifications. The limit of 100% exergetic efficiency, where no exergy destruction takes place, should not be regarded as a practical goal. In practical applications, decisions are usually made regarding the total costs.

Thermodynamic analysis can lead to a better understanding of the overall performance, and eventually to identifying the sources of losses due to irreversibilities in each process in the system (Kingsley Madu 2018). This will not guarantee that useful process modifications or operational changes would be generated; the relations between the energy efficiency and capital cost must be evaluated from the analysis of the overall plant system, and sometimes improved energy efficiency will require more investment. Thermodynamics analysis however has been shown to be of considerable value when applied to systems where an efficient energy conversion is important; exergy analysis also evaluates the merit of an energy conversion in a fuel cells or gas turbines.

1.4 Analysis of vapor compression air conditioning system

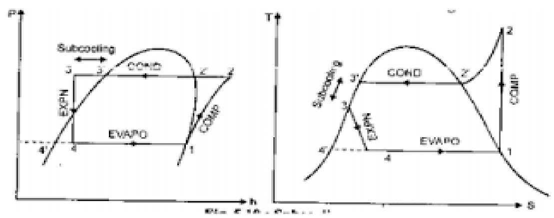


Fig 2 PH and TS diagram of the refrigerating system

1.4.1 Equation of the vapor compressor.

$W_{com} = \dot{m}\,(h_2 - h_1)$ (1)

When $W_{com}$= work of vapor compressor (kW), $h_1$= enthalpy of refrigerant entering the vapor compressor (kJ/kg), $h_2$= enthalpy of refrigerant leaving the vapor compressor (kJ/kg) and $\dot{m}$= mass flow rate of refrigerant ($m^3/s$)

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$X_{COMP} = \dot{m}\,[(h_2 - h_1) - T_0\,(S_2 - S_1)]$ (2)

When $X_{COMP}$= exergy of vapor compressor (kW), $S_1$= entropy of refrigerant entering the vapor compressor(kJ/kg), $S_2$= entropy of refrigerant leaving the vapor compressor (kJ/kg) and $T^0$= ambient temperature (℃).

1.4.2 Equation of heat transfer rate of the condenser.

$Q_{com} = \dot{m}\,(h_2 - h_3)$ (3)

When $Q_{con}$ = heat transfer rate of the condenser (kW), $h_2$= enthalpy of refrigerant leaving the vapor compressor (kJ/kg), $h_3$= enthalpy of refrigerant leaving the condenser (kJ/kg) and $\dot{m}$ =mass flow rate of refrigerant (m3/s)

1.4.3 Equation of the expansion valve, in these process refrigerant flows through the device. It is a pressure reducing process without work or heat transfer, so $h_3 = h_4$

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1.4.4 Equation of thermal exchange in the evaporator

$Q_{Evap} = (h_1 - h_4)$ (4)

When $Q_{Evap}$=heat transfer rate of the evaporator (kW), $h_4$= enthalpy of refrigerant entering the evaporator(kJ/kg)and$h1$= enthalpy of refrigerant leaving the evaporator (kJ/kg).

$X_{evep}$= ṁ [($h_1$−$h_4$) − $T_0$ ($S_1$−$S_4$)] (5)

When $X_{evep}$= exergy of evaporator (kW), $h_4$= entropy of refrigerant entering the evaporator (kJ/kg),

$S_1$= entropy of refrigerant leaving the evaporator (kJ/kg) and

$T_0$= ambient temperature (℃).

COP=. $Q_{Evap/}$ $W_{com}$ (6)

When $Q_{Evap}$=heat transfer rate of the evaporator (kW).and $W_{com}$ = work of vapor compressor (kW).

1.4.6 Equation of Exergy efficiency

$$\dot{\eta}_X = X_{Evap}/X_{COM} \quad (7)$$

When $\dot{\eta}_X$= exergy efficiency of air conditioning system,

$X_{Evap}$ = exergy of evaporator(kW) and $X_{COM}$= exergy of vapor compressor (kW).

The aim of this work is to study and analyses the effect of ambient temperature on the performance of an air-conditioning system in the temperate region. A 20 tons air conditioning system will be designed. The designed system will be analyses thermodynamically. Energy and exergy analysis will be carried out on the system to enable the determination of the effect of ambient temperature on the system. The COP of the designed system will be determined. The mass flow rate of the system designed will also be determined. The effect of the ambient temperature on the compressor will also be determined.

## II. METHODOLOGY

2.1 Equipment and Methodology; This research is the study of the effect of ambient temperature on the performance of an air conditioning system. The energy efficiency and exergy efficiency will be the tools to determine the set out objectives. A 15 tons air conditioning system was designed for this analysis.

The system consists of Wall mounted inverter split type air conditioner cooling capacity 12,000 Btu/h (3.517 kW) using R32 refrigerant. To determine the effect of outdoor temperature on the performance of a split-unit air conditioner, an experiment setup consist of a split-unit air conditioner, and appropriate measurement tools to measure temperature and pressure was designed and fabricated. The vapor compression refrigerating system operates between a pressure of 0.168 bar and 12.19 bars. The refrigerant leaves the evaporator dry saturated and compressed to the condenser pressure. The system is assumed to be compressed isentropically.

## III. RESULT AND DISCUSION

In the analysis of the system, we make use of the steady state flow energy equation. For ease of analysis, it is assumed that changes in kinetic and potential energies are negligible. At point 1 (refer to Fig. 3), and from the saturated refrigerant-134a – Pressure Table.

$P_1$= 0.168 bars,$T_1$= -65 ºC $S_1$= 0.7649 kJ/KgK $v_1$= 0.00650 m3/Kg $h_1$ = 185.38 kJ/Kg

$P_2$=12.19bars, $T_2$= 50$^O$C, $S_2$=$S_1$, $h_2$=?

We note that $S_1$=$S_2$ (given) and also that $P_2$ =$P_3$ but $T_2$ is not $T_3$, thus in order to find the value of $h_2$ we will need to interpolate in the prevailing condenser pressure since $h_2$ is not equal to hg at 12,19 bars.

$$\frac{S_2 - S_1^1}{S_2^{11} - S_2^1} = \frac{h_2 - h_2^1}{h_2^{11} - h_2^1} \quad (8)$$

$$\frac{0.7649-0.7166}{0.7503-0.7155} = \frac{h_2-218.64}{230.33-218.64}$$

$$\frac{0.0483}{0.0343} = \frac{h_2-218.64}{11.69}$$

$h_2$ =235.18 KJ/Kg

At point 3 $h_3$ = 84.94

At point 4 $h_3$ =$h_4$ = 84.94 KJ/Kg

Therefore refrigerating effect = $h_1$- $h_4$ = 185.38-84.94 = 100.44 KJ/Kg

Mass flow rate = m ($h_1$-$h_4$) = Q(kw) (9)

$$\dot{m} = \frac{Q(kw)}{h_1-h_4} = Q = 1KW$$

$$\text{i.e } m = \frac{1}{100.44} = 0.00995$$

Note 1 ton =3.52kw

For the 20 ton A/c =20 X 3.52 =70.4

For a 25ton A/C =25 X 3.52 = 88

Thus m = 70/100.44 =0.701kg

$$COP = \frac{h1-h4}{h2-h1} = \frac{100.44}{235.1-185.38} = \frac{100.44}{49.72} \quad (10)$$

COP (50º) =2.02

Effect of compressor work on the COP

As the ambient temperature increases the compressor does more work and in turn increases the enthalpy of the system. As the enthalpy of the system increases the COP of the system reduces.

For a temperature of 55ºC $h_2$ is calculated using equation (8) and gotten to be 237.31KJ/Kg

For a temperature of 60ºC $h_2$ is calculated using equation (8) and gotten to be 251.68 KJ/Kg

For a temperature of 65ºC $h_2$ is calculated using equation (8) and gotten to be 254.08 KJ/Kg

For a temperature of 70ºC $h_2$ is calculated using equation (8) and gotten to be 256.47 KJ/Kg

COP at 55ºC = 1.93

COP at 60ºC = 1.52

COP at 65ºC = 1.46

COP at 70ºC = 1.41

Work done on the compressor Wcom = m $(h_2-h_1)$

Wcom = 0.701(235.10-185.38) =34.85 J

Exergy of vapor compressor Xcom = m $(h_2-h_1) - T_0 (S_2-S_1)$

Xcom = 0.701(235.10-185.38) – 30º (0.7166-0.7649)

=36.30 J

If the ambient temperature is increased to 35ºC the exergy of the vapor compressor will be

Xcom = 0.701(235.10-185.38) – 35º (0.7166-0.7649)

=36.54 J

If the ambient temperature is increased to 40ºC the exergy of the vapor compressor will be

Xcom = 0.701(235.10-185.38) – 40º (0.7166-0.7649)

=36.78 J

If the ambient temperature is increased to 45ºC the exergy of the vapor compressor will be

Xcom = 0.701(235.10-185.38) – 45º (0.7166-0.7649)

=37.02 J

If the ambient temperature is increased to 50ºC the exergy of the vapor compressor will be

Xcom = 0.701(235.10-185.38) – 50º (0.7166-0.7649)

=37.27 J

If the ambient temperature is increased to 55ºC the exergy of the vapor compressor will be

Xcom = 0.701(235.10-185.38) – 55º (0.7166-0.7649)

=37.51 J

Table 1 Ambient temperature and enthalpy value after compression.

| Ambient temperature (ºC) | Enthalpy value after compression (kJ/kg) |
|---|---|
| 50 | 235.18 |
| 55 | 237.31 |
| 60 | 251.68 |
| 65 | 254.08 |
| 70 | 256.47 |

Table 2 Ambient temperature and the COP

| Ambient temperature (ºC) | COP |
|---|---|
| 50 | 2.02 |
| 55 | 1.93 |
| 60 | 1.52 |
| 65 | 1.46 |
| 70 | 1.41 |

Table 3 Ambient temperature and the corresponding exergy value

| Ambient temperature (ºC) | Exergy value (J) |
|---|---|
| 30 | 36.30 |
| 35 | 36.54 |
| 40 | 36.78 |
| 45 | 37.02 |
| 50 | 37.27 |
| 55 | 37.51 |

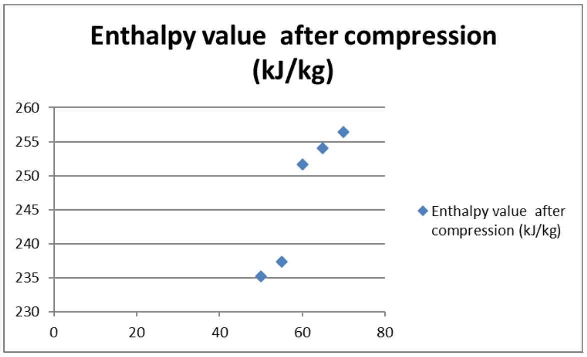

Fig 3. A Graph of enthalpy against ambient temperature

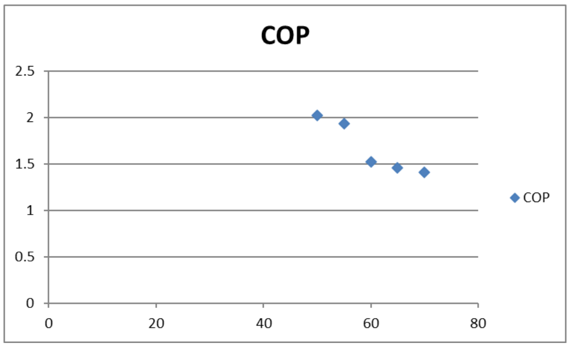

Fig 4. A Graph of COP against ambient temperature.

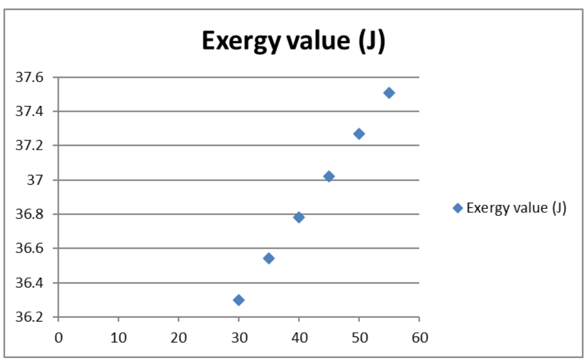

Fig 3 A Graph of the exergy value against the ambient temperature.

## CONCLUSION

The above discussion is based on the ideal vapor-compression refrigeration cycle, and does not take into consideration 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 (if any). The performance of the system, as discussed, corresponds to the parameters that govern the design. The 20 tons capacity air conditioner was successfully designed, and the effect of ambient temperature in the performance of the refrigerating system was studied thermodynamically. The enthalpy value after compression, the coefficient of performance (COP), and the enthalpy values were studied for the design air conditioner at different ambient temperature. It was discovered that the enthalpy increases with increase in ambient temperature as seen in fig1. Furthermore it was also discovered that the coefficient of performance decreases with increase in ambient temperature. The exergy of the system was also found to be increasing with an increase in the ambient temperature.

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