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Comparative Analysis of the Modes of Operation and Co-Efficient of Performance of a Typical Vapor Compression Air-Conditioner and Inverter Air-Conditioner

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ABSTRACT

Demand for air conditioners has continually increased worldwide over the last few years, with high economic countries and temperate region countries being the highest in terms of percentage demand, of which Nigeria is not an exception. With the increased gross domestic product (GDP) and warming climates, demand for room Air-conditioners is expected to further increase, thereby posing a challenge in meeting the demand of electricity consumption. Increased use of non-energy efficient Air-conditioners unarguably has a negative impact on the national grid, especially during periods of high demand, while energy efficient Air-conditioners relieves this impact. In a Typical Vapor Compression Air-conditioner, the compressor runs at a fixed speed and is either ON or OFF, while in an inverter Air-conditioner, the compressor is always on, but power drawn depends on the demand for cooling. The speed of the compressor is adjusted appropriately. In this study, we analytically compared the mode of operation and the COP of a typical vapor compression air-conditioner (VCAS) and an inverter air-conditioner of same capacity using same office under similar operating conditions. From the comparison, it is obvious that the inverter air-conditioner performed better than the vapor compression-air conditioner.

1. Introduction

Recently, power distribution system operators have encountered new challenges to maintain secure and reliable operation with the higher integration of renewable energy sources amid increasing electricity demand. This calls for needs of energy savings in other to mitigate these challenges. Air-conditioner is a very essential electric appliance in all sectors (residential, commercial and industrial). Air-conditioning technologies can be broadly categorized in two groups. The first is based on the hysteresis temperature control and the motor is turned on/off [1-7]. The latter uses inverter to adjust in-feed power to the motor driving the compressor by adjusting the frequency in order to meet the requirement of the thermodynamic process.

2. Comparing Vapor Compression Air-Conditioning System Mode of Operation and an Inverter Air-Conditioning System

2.1 Ideal Vapor Compression Refrigeration Cycle

The Temperature-Entropy (T v s) and Pressure-Enthalpy (p v h) diagram for the ideal vapor compression refrigeration cycle are shown in Fig 1.

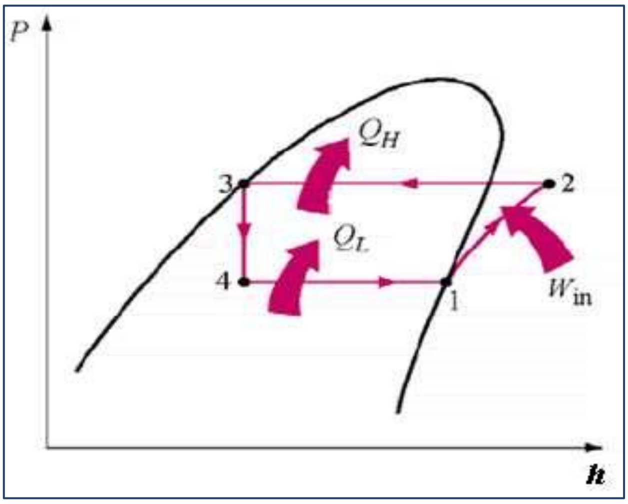
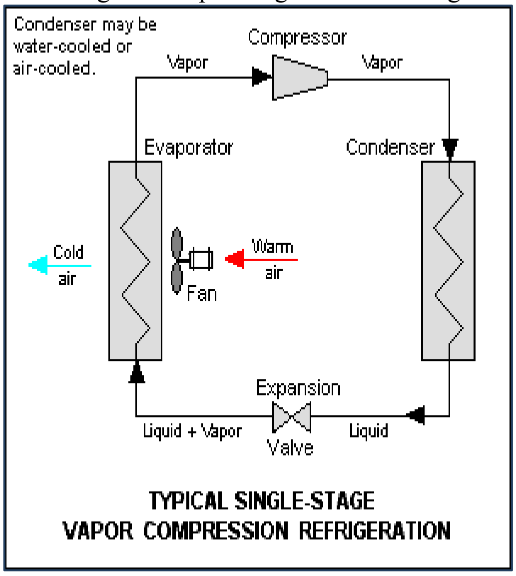
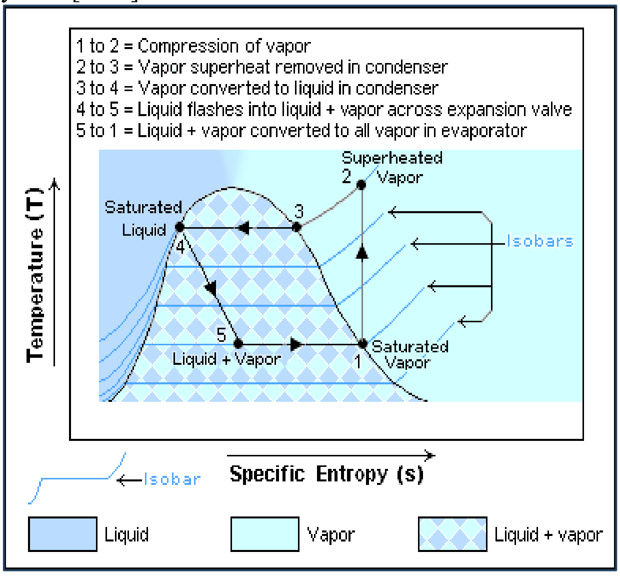


Figure 1: (a) T v s and (b) p v h diagrams for the idea vapor compression refrigeration cycle. Source: Cengel and Boles (1998)

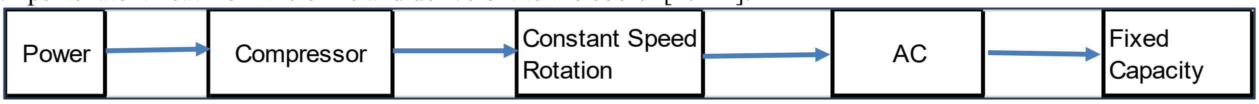
The vapor compression refrigeration system is the most common refrigeration system that is being used nowadays. It is widely used for all purpose refrigeration. It is commonly used for all industrial purposes from a small domestic refrigerator to big air-conditioning plant. The vapor compression refrigeration system is an improved type of air refrigeration system. In this system, a particularly suitable working fluid (Refrigerant) is used to run the whole system. The refrigerant used is circulating throughout the system alternately condensing and evaporating without leaving the system [8-14].





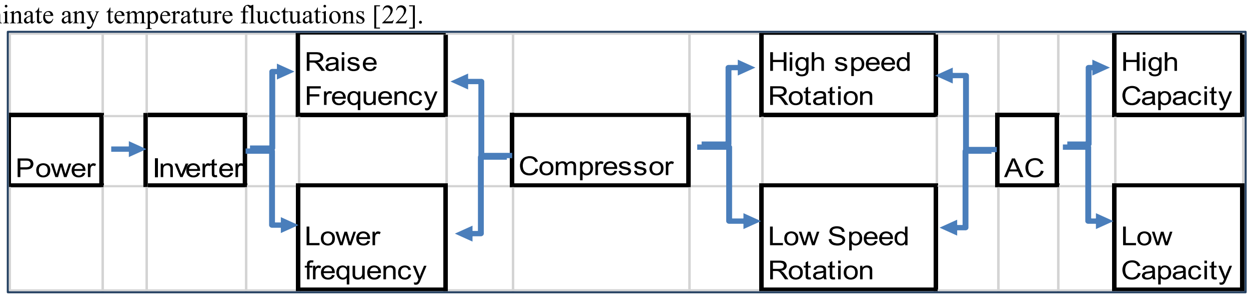
2.2 Mode of Operation of a Vapor-Compression Air-conditioner

A vapor compression refrigeration system is an improved type of air refrigeration system in which a suitable working fluid (refrigerant) is used. It condenses and evaporates at temperatures and pressures close to the atmospheric conditions. The refrigerants, usually, used for this purpose are ammonia (NH3), carbon-dioxide (CO2) and sulphur-dioxide (SO2). These refrigerants, do not leave the system, rather are circulated throughout the system alternately condensing and evaporating. In evaporating, the refrigerant absorbs its latent heat from the brine (saltwater) which is used for circulating it around the cold chamber. While condensing, it gives out its latent heat to the circulating water of the cooler. The vapor compression refrigeration system is, therefore a latent heat pump, as it pumps its latent heat from the brine and delivers it to the cooler [15-21].



2.3 Mode of Operation of an Inverter Air-conditioner

An inverter type air-conditioner adjusts the speed of the compressor to control the refrigerant (gas) flow rate, thereby consuming less current and power. An inverter has precise temperature control and as the set temperature is attained, the unit adjusts its capacity to eliminate any temperature fluctuations [22].



2.4 Difference between an Inverter Air-conditioner and a Vapor compression Air-conditioner

The cooling load of an Air-Conditioner is a variable and depends on room occupancy (number of persons), desired comfort level of the customer (set temperature), outdoor environmental conditions and many other parameters. In most air-conditioners, the air-conditioners' actual cooling load fluctuates.

However, in vapor compression air-conditioners, the system is not designed to handle this variable load, but for the expected peak load. In an air-conditioner, the compressor is the component which consumes electricity. In vapor compression type air-conditioners, the compressor is either ON or OFF. When it is ON, it works at full Air-Conditioning capacity and uses the full amount of electricity it is designed to consume. When the set temperature in the Air-conditioner is achieved, the compressor is cut-off and cooling is stopped. When the thermostat senses that the room temperature has increased, the compressor switches ON again, automatically [23-27]. That means, the compressor is switched ON and OFF intermittently.

The inverter driven Air-conditioners with varying cooling capacity has been studied during the last two decades and the well-known technique is to control the rotational speed of the compressor based on its cooling load. A three-phase induction motor (IM) is generally used as the compressor motor. In an inverter type Air-conditioner, the inverter is used to control the speed of the IM by changing the frequency of the power supply to drive the variable refrigerant flow and thereby regulating temperature of the conditioned space. The variable frequency drive is used to achieve the desired frequency, and the rotational speed will be proportional to the input frequency. This will adjust the flow rate of refrigerant based on the temperature of the room. With this technology, the compressor of the Air-conditioner is always ON, but varies the power input depending on the temperature of the return air and the level set in the thermostat. Hence, the flow of refrigerant is dependent on the cooling needs of the space. Several studies have modelled the variable speed compressor to simulate the inverter Air-conditioner. Some researcher, by their modelling and experimental investigation, found that the refrigerant flow is determined only by the compressor frequency and is independent of the condensation and evaporation temperatures [28]. They also found that the coefficient of performance (COP) of the inverter air conditioner changes slightly with the speed of the compressor, and the optimal frequency which gives the highest COP is usually the basic frequency [29-30].

3. Materials And Study Methodology for Comparing Coefficient of Performance and Efficiency.

Two Air-conditioner units, an inverter and a typical vapor compression Air-conditioner, were tested under similar operating conditions. Both were rated single-phase 240V, 50Hz. Each Air-conditioner unit was mounted on the same wall of an office room and the temperature control settings of the units were set to 26ºC, so that it creates the normal operating load in an office building.

4. Methodology

The energy consumption of the two Air-conditioner units was evaluated by using a Circutor™ power analyzer. The Air-conditioners were operated on alternate days; Vapor compression Air-conditioner on one day, and the inverter Air-conditioner on the following day. Energy consumption was measured in one-minute intervals over 6 consecutive weeks, so that the effect of fluctuation of ambient temperature may be assumed to be cancelled out. Temperature and relative humidity were logged in one minute intervals using data loggers [31-34].

5. Results

Figure 2 and 3 shows the variation of power drawn by the Vapor compression and inverter type Air-conditioners, respectively, operating at similar temperature settings during normal office hours 06:00 to 15:00hrs, under similar (assumed) outdoor conditions

. Fig 2 - Power drawn by the Vapor compression Air-conditioner during Office Hours

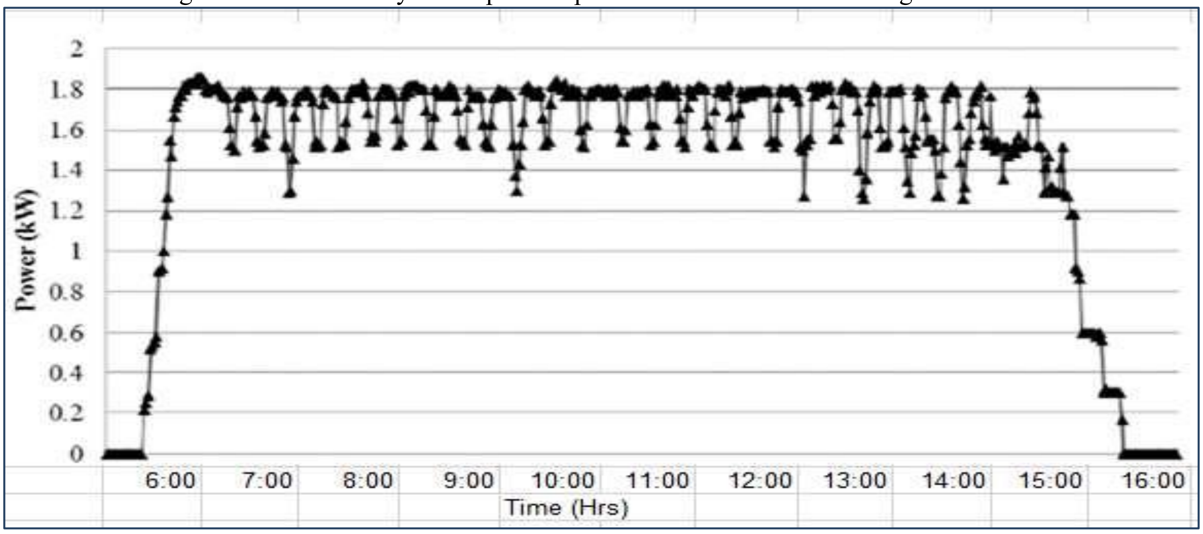


Fig 3 - Power drawn by the Inverter-Type Air-conditioner during Office Hours

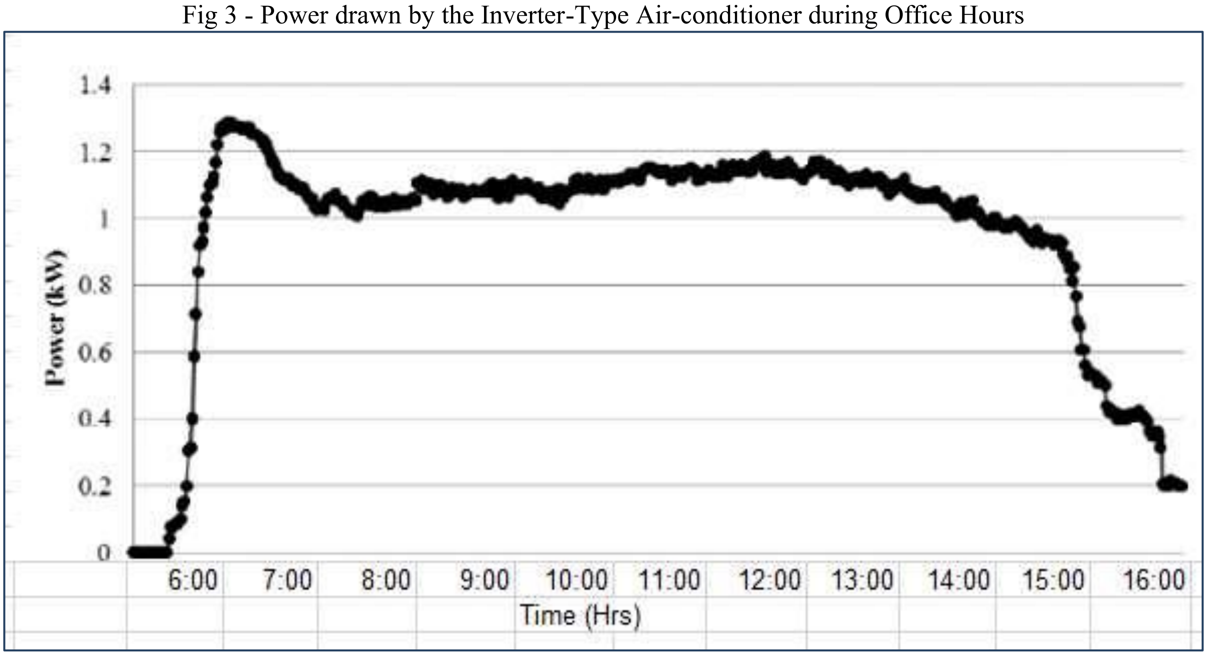


Figure 4 shows the daily energy used in both Air-conditioners. Since the measurement was done over 6 weeks, fluctuations of outdoor conditions are expected to be cancelled out or similar for both Air-conditioners. Since the compressor of Vapor compression Air-conditioners frequently switches ON and OFF, the current and the power consumption of the Air-conditioners fluctuates rapidly [35-39].
The power consumption pattern of an inverter Air-conditioner is smoother than a typical vapor compression air-conditioner because the compressor will not switch between ON and OFF, rather it will modulate.

Fig 4 – Energy drawn over 8 hours (06:30 to 15:30) at a Temperature Setting of 26 ºC

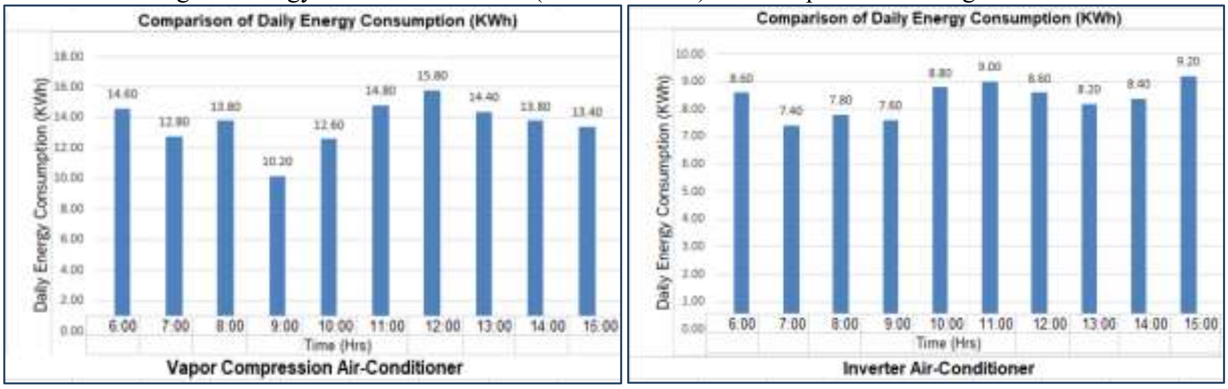


Figure 4. gives the energy consumption of an inverter and vapor compression air-conditioner run in the same space on alternate days for a 6-week period.

Average Energy Consumed = ∑E ÷No. Hrs
Therefore, Energy Consumption in an inverter AC will be
8.60+7.40+7.80+7.60+8.80+9.0+8.60+8.20+8.40+9.20 ÷ 10Hrs
83.60 ÷ 10 = 8.36Kw
While Energy Consumption of a Vapor Compression AC will be
14.60+12.80+13.80+10.20+12.60+14.80+15.80+14.40+13.80+13.40 ÷ 10
136.20 ÷ 10 = 13.62Kw.
Therefore, Co-efficient of Performance for both Air-Conditioners will be given as
COP = Qc / Qw
COP Inv. = 26/8.36 = 3.1
COP vc. = 26/13.62 = 1.9
The daily average energy consumption of the Vapour compression Air-conditioner was 13.62 kWh (for 10-hour operating period) with a COP of 1.9, and the average energy consumption of the inverter type Air-conditioner was 8.36 kWh with a COP of 3.1, for the same period under similar operating conditions. This clearly shows that an Inverter Air-conditioner consumes less energy, is efficient and thus, has a better co-efficient of performance than the Vapor Compression type.

6. Conclusion and Recommendation

Having carried out the analysis for 10hrs daily for a period of 6 weeks with same capacity of ACs, Same room and under same/similar operating condition, and obtained a COP of 3.1 for an inverter type Air-conditioner, and a COP of 1.9 for a vapor compression air-conditioner, It is concluded that inverter technology can save about 35% of energy over a Vapor Compression Air-Conditioner. Also, considering their mode of operation, the inverter type Air-conditioner have an almost smooth operation circle as the compressors continuously modulates depending on cooling demands and is more silent and have less vibration, while the vapor compression type air-conditioner does not have a smooth operating circle as the compressor intermittently switches ON/OFF, these in turn increases noise and vibration. With the expected growth of Air-Conditioner use and ambient temperature rise due to global warming, inverter technology can provide significant savings. It is therefore, recommended that when purchasing an Air-conditioner, Consumers should go for an inverter type Air-conditioner in other to save energy, money; and reduce noise and vibration.

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