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Analysis Of Energy Efficiency And Environmental Impacts With The New Inverter Air Conditioning Technology

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Abstract:
Air conditioning systems are known for their high energy consumption and the environmental impacts they can cause, especially with regard to greenhouse gas emissions. However, inverter air conditioning systems are a more advanced technology that can offer significant improvements in terms of energy efficiency and reduced environmental impacts. Inverter air conditioning systems use a variable speed compressor, which allows the unit to adjust the compressor speed to meet cooling or heating needs. This means that the compressor does not have to switch on and off continuously, which reduces energy consumption and increases system life. In addition, inverter air conditioning systems are designed to operate more quietly and produce less noise than conventional systems. In Brazil, where demand for air conditioning systems is high, the use of inverter air conditioning systems can have a significant impact on reducing energy consumption and greenhouse gas emissions. In addition, Brazilian authorities have implemented measures to encourage the adoption of energy efficient technologies, including energy efficiency labeling programs to help consumers identify the most efficient appliances. However, it is important to remember that the energy efficiency of an inverter air conditioning system depends on its proper installation and maintenance. It is necessary that the system be sized correctly for the space in which it will be installed and that a regular maintenance program be carried out to ensure that the system is operating efficiently. In summary, the use of inverter air conditioning systems in Brazil can offer significant benefits in terms of energy efficiency and reduced environmental impacts, especially when combined with government incentive measures and proper installation and maintenance practices. It is with these first fruits that this project will explore the need for technological changes for refrigeration systems, proving their efficiency both in terms of energy and the environment.
Key words: *Air conditioning, inverter, compressor, consumption, energy efficiency, Environmental Impacts.*

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I. INTRODUCTION

The importance of air conditioning has grown in such a way that new solutions have emerged in terms of systems and equipment, with increasingly specific and diversified technologies. This evolution also created a challenge for air conditioning engineers: determining the most appropriate climate control strategy for the characteristics of the plant, defining the type of system to be used, linking factors such as compliance with current regulatory requirements, energy efficiency, initial cost and interface with other objects.

All air conditioning systems are based on the exchange of air heat with the refrigeration cycle, which consists of a set of thermodynamic processes in a given refrigerant. They are: evaporation, compression, condensation and expansion. The application of the refrigeration cycle has been verified in many other devices present in everyday life such as refrigerators, freezers, heaters, etc. The main criterion for classifying the air conditioning system is the way in which heat exchange occurs between the environment and the refrigeration circuit, which can be a direct or indirect expansion system. Until the 1990s, the Brazilian home appliance market was limited to window units, when smaller capacity split units began to be sold. Since it became very popular, division was mistakenly adopted as a solution without prior study. This is happening in the market due to the lack of specialized professionals in the field of HVAC, the lack of integration between the engineering and architecture sectors and the mistaken mentality that the lowest initial price is the best option to adopt. The variable refrigerant flow system, known by the acronym VRF for "Variable Refrigerant Flow", operates with partial compressor load, offering two advantages: energy efficiency and individual attention to the environment. However, like the split, it needs an auxiliary air recovery system to meet the technical standards for air quality (see standard NBR ABNT 16401-3:2008). [1].

The first reported air conditioning system in history was used to remove the relative humidity (RH) in a press where newspapers were printed in mid-1902, which was cloudy if the RH was too high. Since then, air conditioners, popularly called “air conditioners”, have undergone numerous improvements. Currently, an air conditioner has several functions such as heating, cooling, dehumidification, ventilation, air filtration, among others. In most cases, they are used to provide thermal comfort to users in a given environment. The energy performance of residential air conditioners is a subject that has been frequently addressed nowadays, mainly due to the issue of global warming, since the thermal comfort of environments is an item responsible for a significant portion of CO_2 emissions in the environment. The use of air conditioners with high energy efficiency can delay the construction of power generation plants, saving resources that are relatively limited in these countries.

It is of interest to investigate the main causes of the reduction in consumption achieved by the inverter conditioner. When addressing this issue qualitatively, some doubts arise at first. It is argued that, if on the one hand the inverter conditioner adapts to the reduced cooling demand by reducing the compressor speed, allowing the reduction of its energy consumption due to the reduction of the refrigerant flow rate, on the other hand, despite the conventional on-off type conditioner operating at full load under these same conditions, the compressor is turned on only a fraction of the time. Which factor is predominant?

II. LITERATURE REVIEW

History

Willis Carrier is credited with the invention of the first air conditioning system in 1902. This equipment was destined for a printing company in New York, and had the function of cooling and removing humidity from the environment, since the prints had defects or stains mainly due to the high humidity. In 1914, Carrier developed the first residential air conditioner comparable to current models. In 1950, household appliances began to be produced on a large scale and reached the global market [2]. The carrier and other authorities at the time determined that an air conditioning system should fulfill at least four functions: temperature control, humidity control, circulation/ventilation control and air purification, and even a filter to keep out bacteria. mites and viruses. This technology at the time came from a problem that a company in New York was going through. When printing on paper, the very hot summer weather and high humidity caused the paper to absorb this moisture, causing prints to be blurry and out of focus. He created a process that cooled the air by circulating it through artificially cooled ducts, which could also reduce the humidity in the air. This was the first continuous mechanical process air conditioner in history. Based on this experience, the system was adopted by several industries from different segments, such as textile industry, paper industry, pharmaceuticals, tobacco and some commercial installations.

In 1914, Carrier developed a device for residential use, much larger and simpler than the current air conditioner, and also designed the first air conditioner for hospitals, which was developed with the aim of increasing the humidity in the nursery (for babies born prematurely). at Allegheny Hospital in Pittsburgh. In the 1930s, Willys Carrier also developed an air conditioning system for skyscrapers with high velocity air distribution, which saved more space than the products in use at the time [3].

Air distribution at high speed through "Weathermaster" ducts, created in 1939, saved more space than the systems used at the time. In the mid-1950s, residential models of air conditioning began to be mass-produced, the year Willis Carrier died. Demand was huge, running out of stock in just two weeks. In the following decade, these products were no longer new. From this, a worldwide market in constant expansion began, with plenty of room for technological development and new products, until today. The current air conditioners, which are used to control the temperature of closed environments, come from the creation of this mechanical process to condition the air, created by the Carrier.

Functions and principles

An air conditioner is a device designed to condition the indoor air, keeping its temperature and humidity under control, leaving environments at pleasant temperatures, creating a feeling of thermal comfort (heating or cooling) or even in certain environments. essential, such as CPD, laboratories, hospital units, radiology, UPS and others. The principle of operation of air conditioning is nothing more than a change in the temperature of the ambient air, through the passage of air through the coil of the evaporator, which by contact has a drop or increase in the temperature of the air, depending on the cycle used, lowering the temperature of air and the relative humidity of the air. Ambient air is sucked in by a fan and passes through the evaporator, passing through a coil filled with refrigerant gas at a temperature of 7°C and in liquid state. In contact with the cold coil, the air is cooled and returned to the environment. By absorbing heat from the air, the gas changes state inside the coil and transforms, then enters the electric compressor. This part, which produces the noise of the device, compresses until it becomes a hot gas under high pressure, at 52°C. As a result, it becomes liquid again even before it reaches 7°C as it is under high pressure. Another fan blows the remaining warm air out into the street. [4].

The choice of a cooling/heating system must take into account some fundamental aspects: price, energy consumption, functionality and, above all, thermal comfort. In strictly economic terms, but if price isn't your only concern, then maybe it is. However, strictly in terms of thermal comfort, there may be better systems. If the option is for air conditioning, not only for the cold, but also for the heat, the lower cost will have the counterpart of less comfort. Experts recall the advantage of air filtration provided by air conditioning, which significantly reduces the number of impurities suspended in the air. They also explain that a well-dimensioned system guarantees uniform air distribution, filters the air and can allow for renewal, avoiding its saturation.

In addition to cost, another important factor when choosing an air conditioning system is energy consumption. Modern air conditioning equipment uses a heat pump system "inverting the cycle for heating", which reduces consumption.

The main objective of air conditioning is to leave the environment at a pleasant temperature, creating a feeling of thermal comfort (heating or cooling) or even helping activities carried out in an environment where its use is necessary, such as laboratories, hospitals, processing centers, etc.

The operating principle of air conditioning is based on changing the ambient temperature, through the passage of air through the coil located in the evaporator. By contact, the air undergoes a decrease or increase in temperature, depending on the cycle used, in both cases the humidity is removed from the conditioned environment, decreasing the relative humidity of the air. Upon reaching the desired temperature, the reading is taken through the sensor located on the evaporator. And this, in turn, turns off the compressor on the outdoor unit. If any deviation occurs in the predicted temperature, the compressor is activated again, responsible for the gas circulation inside the system [5].

Figure 1 illustrates the basic cooling cycle. Not shown in the image, but important in the cycle, the fan of the indoor unit does an important job, the heat is removed from the environment through the air circulation that this fan promotes. Air enters the evaporator at ambient temperature, loses heat to the evaporator coil which is at a very low temperature, and is forced back into the room at a lower temperature. The cooling process consists of circulating the refrigerant gas between the condenser and the evaporator using the mechanical energy provided by the compressor. When entering the compressor, the gas is in gaseous form and under low pressure. In the compressor, the gas is compressed and its temperature increases. When this gas cools down through the external fan, it condenses into a saturated liquid. Under high pressure, the gas becomes a saturated liquid when it loses heat to the external environment, so when it returns to the evaporator, it delivers this air to the room.the evaporator, it delivers this air to the room.

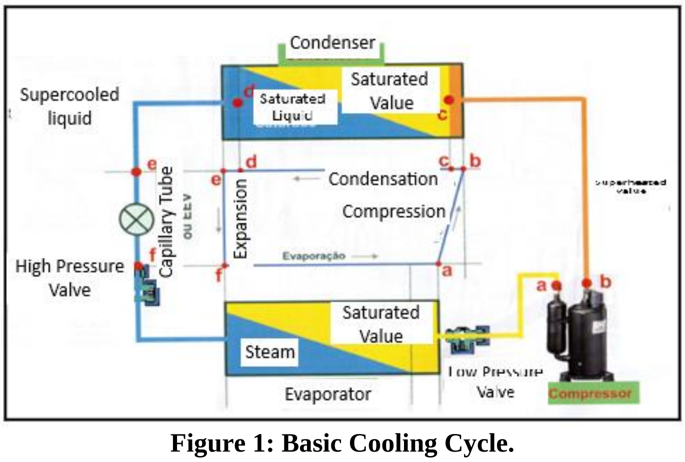


Figure 1: Basic Cooling Cycle.
Source: [5]

The compressor is the element that consumes the most electrical energy in the air conditioning system, reaching up to 90% of consumption in a residential air conditioning system, so it must be energy efficient to reduce electrical energy consumption. behave according to the speed, which is why it is common for the air conditioning compressor to suffer disturbances in the electrical network, which is usually manifested by flickering light bulbs and momentary voltage drops. For compressors in which the gas is not yet compressed, the resistant torque behaves according to the curve as shown in Figure 2, that is, it needs a low torque during start-up and increases according to the increase in speed, reaching the maximum at rated speed.

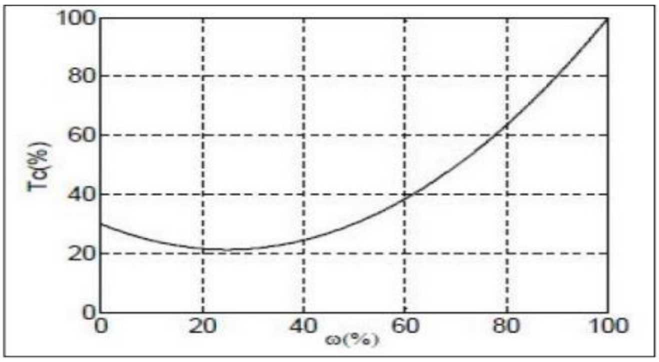


Figure 2: Compressor Gas Compression Curve.
Source: [5].

The resisting torque remains constant after the motor reaches rated speed. When the compressor is turned off, it can only be turned on again when the gas is decompressed, as the engine must be turned on with the compressor unloaded. Through tests on some models of air conditioners, it was observed that the minimum time between turning off the compressor and turning it on again is 3 minutes, this time is the minimum necessary to decompress the gas, avoiding unwanted increases in current.

Types of Air Conditioning

According to [6], air conditioning systems can be classified as follows:
- Direct expansion system; (every theme of the article is applied in this system)
- Indirect expansion system.

The system is called direct expansion when the air is cooled directly by the refrigerant. Applications are as follows: Window Devices; Divisions; Independent; Split Inverter; Split Cassette. Not all air conditioners have the same functions. There are several types of systems, where each one has a technology, or a different characteristic. Some systems allow only refrigeration, dehumidification, ventilation and filtration. Others that have a reverse cycle, in addition to the functions of the previous one, also allow heating and humidification. The main difference between them is the presence of solenoid valve that allows the inversion of the refrigerant gas flow. Both need a control device to maintain the temperature programmed by the user, and it is increasingly common to use automation to provide this control.

Split models are currently the most used due to lower noise in an air-conditioned environment. The division are external condensing unit and the internal evaporator unit respectively. With this device, a lower noise level can be achieved in a climate-controlled environment, as the compressor is located in the outdoor unit (condenser). The thermal interconnection between the units is made through a cooling pipe, in copper or aluminum [7].

The split-type air conditioning system consists of two pieces of equipment interconnected by refrigeration tubes, a condensing unit (external) and an evaporative unit (internal). The distances between the parts that make up the system, as well as the differences in the levels used, depend on the characteristics of the system to be installed. System advantages: The indoor evaporator unit can be controlled by remote control, Lower noise level due to the distance at which the outdoor condensing unit can be installed, its installation is adaptable to environments where it is not possible to install a conventional air conditioner (window type). Components of a split air conditioning system: Condensing unit, evaporator, cooling piping, electrical network and drain. The outdoor unit, located outside the air conditioning room, contains components such as compressor, condenser and expansion valve. The indoor unit consists of an evaporator and a cooling fan. See below in Table 1 the advantages and disadvantages of this air conditioner.

Table 1 – Advantages or disadvantages of split-type air conditioning.

Advantages	Disadvantages
Greater versatility than window-type air conditioners.	Higher purchase and installation price.
More attractive than window-type air conditioners.	Not suitable for multi-storey buildings.
They are silent on the inside (evaporating part).	They are noisy on the outside (condenser part).

Source: [7].

The design and execution of the electrical network must meet the requirements of [8] for low voltage installations and [9] for medium voltage installations. It is recommended that small split units using a recirculation fan and other system components dispersed throughout the building be powered from the system switchboard; and is not connected to lighting or other electrical circuits in the building. They are installed in the evaporation unit of the equipment through PVC pipes to drain the water that is created during the evaporation process. Pipes are usually located inside the walls.

The compressor of a conventional split air conditioner, also called an on/off compressor, turns on at maximum speed while the unit acclimatizes and turns off as soon as the room reaches the desired temperature. This causes the device to reach a very high consumption when the compressor is on. Whenever the ambient temperature presents any disturbance, for example, when the external temperature changes to the point of interfering with the internal temperature or when doors and windows are opened, the compressor turns on again to meet the user's need to leave the environment at the desired temperature. and restart this power spike occurs. Depending on the construction, compressors can be divided into: hermetic, semi-hermetic and open.

According to [11-13] the refrigeration system must have its capacity properly controlled so that the temperature inside the refrigerated environment remains within the desired value. In systems with conventional compressors, thermostats are used to turn the compressor on and off, while in systems with variable speed compressors, the rotation of the equipment is adjusted to the needs of the system. A variable speed compressor or inverter works with a frequency converter that receives a signal from sensors connected to the refrigerated environment.

The motor of the inverter compressor, as shown in figure 3, starts smoothly, its operation starts with a lower rotation speed, different from the conventional compressor. Once started, the inverter compressor continuously adjusts the current consumed to ensure proper rotation, according to the required application. According to Embraco, a pioneer manufacturer of variable speed compressors, this type of equipment generates, on average, 25% less energy consumption in refrigeration systems, compared to systems equipped with conventional on-off compressors [14].

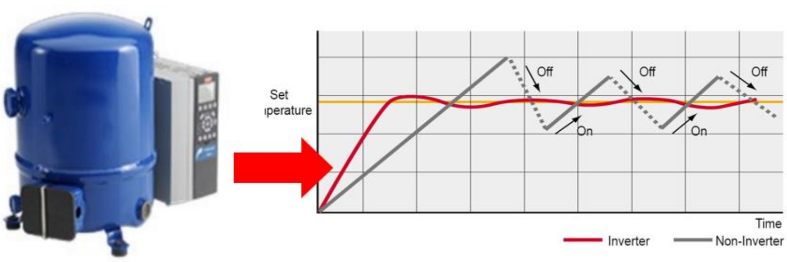


Figure 3 Inverter compressor motor.
Source: [14].

Other advantages were raised by [15] regarding the use of variable speed compressors, and they are: Reduction of fluctuations in temperature and humidity in the refrigerated environment, Less time for lowering the temperature, Reduction in generated noise. Frequency inverter is an electrical/electronic equipment that can provide more advanced control in motors and provide smooth drive to motors. The equipment receives a sinusoidal signal of fixed amplitude and converts it into a signal modulated by Pulse Width Modulation or Pulse Width Modulation (PWM), in English, this signal conversion makes it possible to vary the motor speed.

When the temperature in the refrigerated environment is within ideal levels, the compressor speed is reduced, however, when the temperature in the refrigerated environment increases, the compressor speed is increased to reduce this temperature as quickly as possible. The motor of the inverter compressor starts smoothly, its operation starts with a lower rotation speed, different from the conventional compressor. Once started, the inverter compressor continuously adjusts the current consumed to ensure proper rotation, according to the required application. Figure 4 shows a comparison of the operation of a conventional air conditioning system and an inverter type.

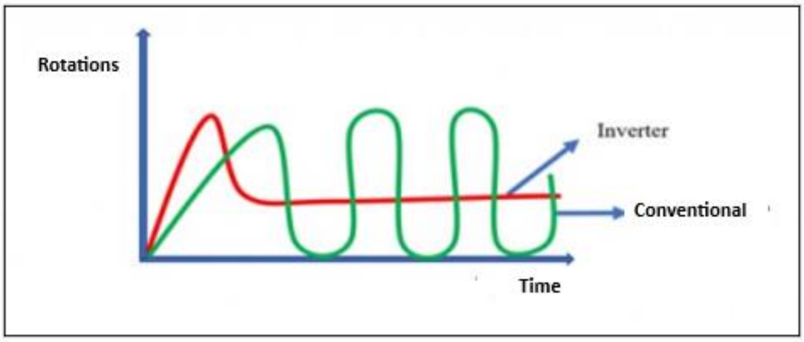


Figure 4: Conventional and Inverter air conditioning operation.
Source: [16].

Split inverter air conditioning is becoming popular due to its energy-saving approach and less impact on the environment. Traditionally, the compressor used in a common air conditioning system is of the on/off type, that is, it runs at maximum capacity or none at all. In the air conditioning with inverter technology, the compressor does not turn off all the time. What happens is the compressor speed variation, which reduces energy consumption when it is detected that the environment needs less cooling. This technology also reduces the energy peaks reached at the beginning of each operation. As they do not work on an on/off basis, appliances that have inverter technology have a much lower variation in the temperature of the air-conditioned environment compared to other technologies. Table 2 presents the advantages and disadvantages of air conditioners that feature inverter technology.

Table 2: The advantages and disadvantages of Inverter Air Conditioning.

Advantages	Disadvantages
Higher efficiency compared to traditional models.	More expensive than traditional models.
Smaller ambient temperature variation.	Maintenance is more expensive due to the technology employed.

Source: [17].

Types of technology

In the last decade, the refrigeration and air conditioning sector underwent major changes due to discussions and analyzes of the environmental impacts caused by the elimination of CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons). After the Montreal Protocol, in 1987, Brazil undertook to comply with the table of substances that deplete the ozone layer (ODS). As this is a federal law, the designer must be aware of illegal refrigerants. According to the aforementioned Protocol, the designer must, if possible, opt for equipment and technologies that use refrigerants that are less harmful to the environment, taking into account the cost factor and the availability of equipment on the market. The designer should pay attention to Ordinance 4059/2001, which regulates Law 10.295/2001, which provides for the National Policy for Energy Conservation. This regulation establishes the maximum levels of energy consumption, that is, the minimum energy efficiency, of energy-consuming machines and devices produced or sold in the country, as well as constructed buildings, determined based on technical indicators and special regulations, with coordination. The seal is granted in two phases: first, in this initial phase of the project and, after completion of the work, an inspection is carried out to confirm or modify the consumption label of the facilities by the IGAE (General Inspection of Economic Activities). It is up to the contractor, together with the designer, to estimate the efficiency range to be sought in the project, within classes A, B, C, D and E, as stated in the National Energy Conservation Label.

From the preliminary examination of the thermal load, the designer must carry out a comparative study between the possible systems that are being designed, confronting the peculiarities of each system, such as the space required for installation, energy efficiency, maintenance and operation costs, simplicity of the system. plant and equipment noise levels. The guidelines, the catalogs and technical manuals of air conditioning equipment suppliers, the [18] energy performance tables and the main equipment selection criteria, given in [1] can be consulted. implemented can be used.

Typical air conditioning installations can be divided into two groups: direct expansion systems and indirect expansion systems. The first system is unique because the refrigerant contained in the coil, when evaporating, directly cools the air in contact with it. In an inverter system, when the air conditioning system is activated, the compressor will run at full speed to quickly reach the desired temperature. When reaching this temperature, unlike conventional air conditioning systems that turn the compressor on and off, inverter units constantly adjust and change the speed of the compressor to maintain the desired temperature with minimal fluctuations to ensure that your comfort is not compromised.

The capacity of an inverter system varies to meet the requirements of the space being conditioned, so this system can be more energy efficient than a constant speed compressor. They are independent air conditioners that contain all the necessary equipment to improve air treatment, such as: filtration, refrigeration, humidification, heating, dehumidification and air movement. The inverter technology, present in the most modern air conditioners, can be compared to the technology that exists in a car, where the greater the acceleration, the faster the movement. Thus, it increases or decreases the speed of the compressor motor according to the need for cooling, as it is capable of operating, for example, at nominal speed, at 50% of the speed. The inverter unit will gradually increase or decrease its heat exchange capacity with the change in compressor speed, adapting to the needs of the environment intended for cooling or heating. In devices that do not have inverter technology, that is, non-inverter units (on-off), there is no acceleration or deceleration of the rotation of the compressor electric motor, in this case the compressor will work with maximum rotation and power until it is turned off when it reaches the desired temperature or until the device is turned off. The air conditioning has a compressor that drives an induction electric motor. For low-capacity equipment, this motor is usually a single-phase type. This motor needs an auxiliary winding to produce the starting torque to create a rotating magnetic field. All starting methods aim to offset the auxiliary winding current by approximately 90° with respect to the main winding current. Such a motor has lower efficiency, but is simpler and cheaper, and, moreover, its arrangement makes the permanent capacitor work as a filter for vibrations caused by flux waves and magnetomotive force rotating in opposite directions. The most common types of motors with starting torque creation are: Motor with auxiliary winding (split phase); Motor with starting capacitor; Motor with permanent capacitor; Motor with starting and permanent capacitor.

Figure 5 shows the starting torque curves for single-phase motors. This curve is directly related to the electric current of the motor, but at the moment of starting, to break the inertia, even the permanent capacitor motor, presents an expressive current that can reach 6 times the nominal current.

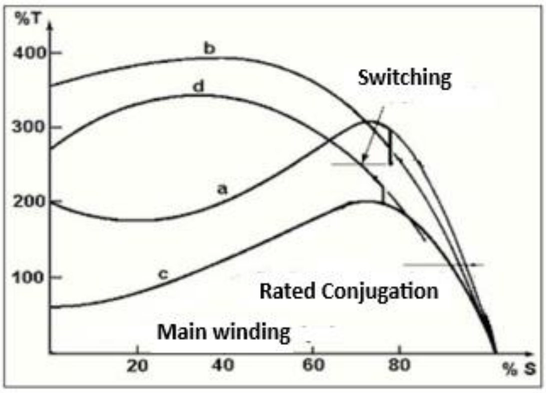


Figure 5: Starting torque curve for single-phase motors.
Source: [14].

Air conditioning systems include their single-phase motors that drive the compressors through a simple relay, which acts as an on/off switch, causing large electrical currents at start-up and interference in other electrical and electronic equipment connected to the same electrical network. Soft-starters are microprocessor-based static switches designed to accelerate/decelerate (start/stop) and protect three-phase induction motors. A soft starter changes the motor speed only when starting and stopping, so it is common to use switches that promote current deviation by short-circuiting the anode and cathode of the thyristor (bypass) when the motor is on. in mode, that is, the thyristors are turned off and the relay closes the contact between the electrical network and the motor in the period after the start and before the shutdown, providing a longer useful life, a reduction in the operating temperature and a reduction in the conduction losses of the thyristors. Figure 6 shows a sinusoidal voltage waveform, where the envelope is the voltage from the electrical network and the part marked in black is theoretically the voltage delivered to the electric motor during starting and during stopping. There is a gradual increase in the voltage delivered to the motor during starting and a reduction during stopping, thus providing smooth starting/stopping.

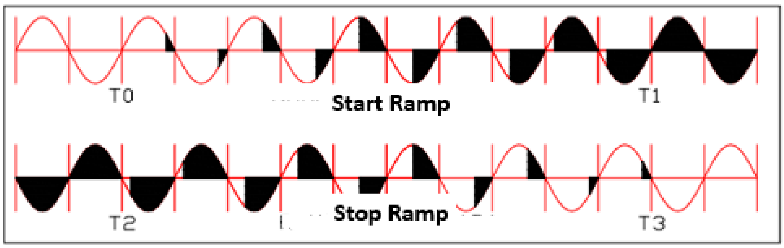


Figure 6: Voltage sine waveform.
Source: [14].

Energy efficiency

The energy efficiency rating (EER) of an air conditioner is its BTU capacity divided by its consumption. If, for example, a 10,000 BTU air conditioner consumes 1,200 watts, its EER will be 8.3 (10,000 BTU/1,200 watts). Obviously, you want the EER to be as high as possible, but typically, a higher EER comes with a high price. The economy is a factor that is directly related to energy consumption in the country, that is, the greater the country's energy mix, the greater its economic development. When considering the economic growth of Brazil, it is noticed that the sectors that contribute the most are the industrial, commercial and residential sectors. States that in the residential and commercial sectors, energy consumption in terms of air conditioning is around 20% and 47% respectively. This shows that the use of air conditioners is one of the main factors responsible for the consumption of electricity in a residence or building [18]. One of the ways to get around this situation is to replace outdated technologies with new ones with better energy performance. States that the Inverter technology is responsible for annual savings of approximately 30% compared to conventional devices, because, unlike conventional technology in which the air conditioning compressor operates in only two states, that is, on/off, Inverter technology has the rotary control function of the compressor, which controls the power supplied to it. Still, according to the same author, the use of Inverter technology allows a faster reduction of the ambient temperature, using only 30% of the time required that a conventional model uses for the same task. It should also be noted that the temperature variation for the conventional model is ± 3º Celsius, while for the Inverter model it is only ± 0.5º Celsius [19][20].

III. MATERIALS AND METHODS

Procedures (STEPS)

Data reading (1st STAGE)

The study complied with the following inclusion criteria: studies that address the issue of split on/off and inverter air conditioning models. Data collection was based on studies published in electronic databases: Google Scholar, SciELO (Brazil Scientific Electronic Library Online) and had an active search started in February 2022 with the help of the following descriptors: Air conditioning, inverter, split on/off. A form-type data collection instrument was developed, which included the following items: Year of publication, authors, journal where it was published, study population and sample, objectives, main results and conclusion, which aim to extract and organize information necessary to achieve the objectives proposed for this research.

Data analysis method (2nd STEP)

The electronic search evaluated whether the titles of the studies fit the objectives of the project, after which the abstracts were read so that the articles could be read in full. The studies underwent a methodological quality assessment using the Assessment of Multiple Systematic Reviews (AMSTAR) scale, an instrument that seeks evidence of validity and reliability of certain studies. Articles that met the eligibility criteria were part of this study.

Works issues (3th STAGE)

This work had as main objective the selection of split-type air conditioners and their required quantity, in order to make a comparison between conventional air conditioner technologies and inverter air conditioners. There was also concern about the quality of electrical energy, as in systems with high power motors and compressors, they cause disturbances in the electrical network.

Experimental tests on the circuit (4th STAGE)

In order to understand the functioning of the activation system of the components of the condensing unit of the Split model air conditioners, the operation of the circuit was studied, where each electrical component had its activation monitored. With the observation of these, the activation cycle and the on times of the compressor, external fan and solenoid valve could be defined. When turning on the Split(s) to heat the environment, the solenoid valve is initially turned on, which reverses the flow of the refrigerant, activating the fan and the compressor.

Advantages and limitations of the research (6th STEP)

Experimental characterization was necessary due to the lack of reference material, as well as the limited and partial information available in the technical manuals that accompany the devices. However, the elaboration of this work with the methodology employed was of great value for the academic field, since a more in-depth study, bringing together articles that deal with the same theme, contributed directly to updating the theme in question, bringing improvements and proposals for changes. to improve the subject.

Iv. Application Of Results And Discussions: Application Of The Case Study

Initial Presentation of Results

Inverter air conditioning technology has achieved good results because of its energy efficiency, which means it uses less energy than conventional air conditioning models. This is because inverter systems continually adjust the compressor speed to maintain the desired temperature, rather than simply turning the compressor on and off. This allows the system to operate over a wider capacity range, adapting to the cooling or heating demand of the environment. In addition, inverter systems also have a lower environmental impact as they use less energy and therefore emit less greenhouse gases. They also have a longer lifespan than conventional models, which means less waste of materials and natural resources. However, it is important to remember that the energy efficiency of an inverter air conditioner depends on a number of factors, such as the size of the room, the quality of the installation, proper maintenance and correct use. If an inverter system is poorly dimensioned or poorly installed, its energy efficiency can be compromised. In addition, inverter technology can be more expensive than conventional models, which can be a barrier to large-scale adoption. In summary, inverter air conditioning technology is an effective solution to increase energy efficiency and reduce the environmental impacts of air conditioning systems. In this chapter we will make an analysis of comparative results in the calorimetry laboratory proving the important results of inverter air conditioning technology for the benefit of society as a whole.

Calorimetry Laboratory for Air Conditioning Tests

The calorimetry laboratory for air conditioning tests was designed with the ability to control environmental variables, such as temperature, humidity, air flow and pressure. For this, it is common to use environmental chambers with precise temperature control and humidity, as well as fans to control air flow. Tests performed in the air conditioning testing calorimetry lab may include measuring cooling capacity, energy efficiency, compressor efficiency, fan efficiency, and heat exchanger efficiency. The results of this test will help this project improve the performance of its equipment and help consumers make informed decisions when choosing an air conditioner.

Results of Comparative Tests between On/Off and Inverter Air Conditioning models in the Calorimeter laboratory.

Energy Efficiency Test in Air Conditioning of 9000BTUs On/Off and Inverter

As shown in Tables 3 and 4, the result of the Psychrometric Calorimeter test shows that:

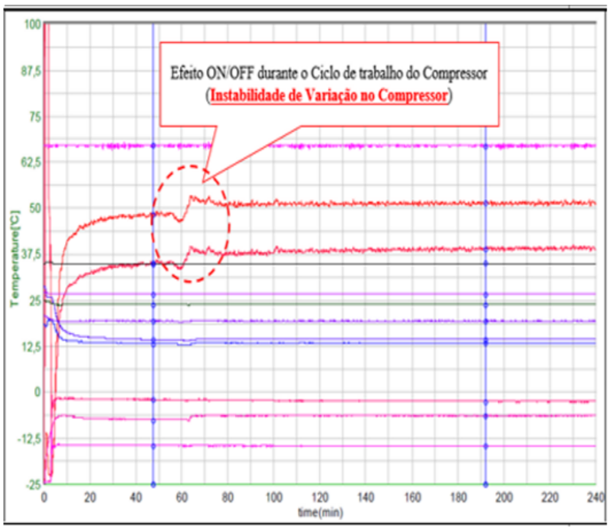
The Model 9000BTUs On/Off Compressor instability time due to the compressor operating at 2 speeds (on and off). When the room temperature reaches the limit set on the thermostat, the compressor is activated and runs at maximum capacity until the desired temperature is reached. After that, the compressor is turned off until the temperature again rises above the threshold. with that, the AC signal variation does not allow an immediate cooling instability, as shown in Figure 7 and the result in table 3.

The Model 9000BTUs Inverter Compressor is capable of operating over a range of variable speeds. It is equipped with a variable speed motor, electronically controlled by a PWM control pulse coming from the inverter circuit. This allows the compressor to continuously adjust its rotation speed to match the ambient thermal load. Precise control of the inverter compressor's cooling capacity keeps the ambient temperature more stable, avoiding sudden fluctuations. Less noise in continuous operation and the operation at lower speeds for the inverter compressor contribute to a quieter environment. Smooth operation and the absence of frequent start/stop cycles reduce compressor wear, extending compressor life. In general, the inverter compressor provides a more efficient, comfortable and silent operation of the air conditioning system compared to the conventional compressor. as shown in Figure 8 and the result in Table 4.

Table 4: Psychrometric Calorimeter Data Sheet (On/Off) _before.

Psychimetric Calorimeter Data Sheet *(ON/OFF)*									
RAC TYPE ON/OFF		**Model**			AS09UBTXAZ				
		Manufacturer			Wind Free				
		Type			Cooling				
		REFRIGERANT CHARGE (gram)			600g (R22)				
		Condition			Cooling steady state				
		Supply voltage (v)			AC 220v				
		CAPACITY (Btu/h)			9000				
		Power(w)			819 WATT				
		Current (amp)			4(A)				
MEASURING DATA		10 min	20 min	30 min	40 min	50 min	60 min	70 min	Average
Capacity	Btu/h	9141,3	9140,0	9144,7	9146,3	9141,3	9152,8	9159,6	9146,6
ERR	Btu/hW	10,196	10,199	10,219	10,222	10,219	10,231	10,254	10,22
Power Input	W	896,5	896,2	894,9	894,8	894,5	894,6	893,3	895,0
Current	A	4,09	4,09	4,08	4,08	4,08	4,08	4,08	4,08
Voltage	V	220,3	220,3	220,3	220,3	220,3	220,3	220,3	220,3
Power Factor	%	99,48	99,48	99,48	99,47	99,48	99,48	99,48	99,48

Source:Authors, (2023).



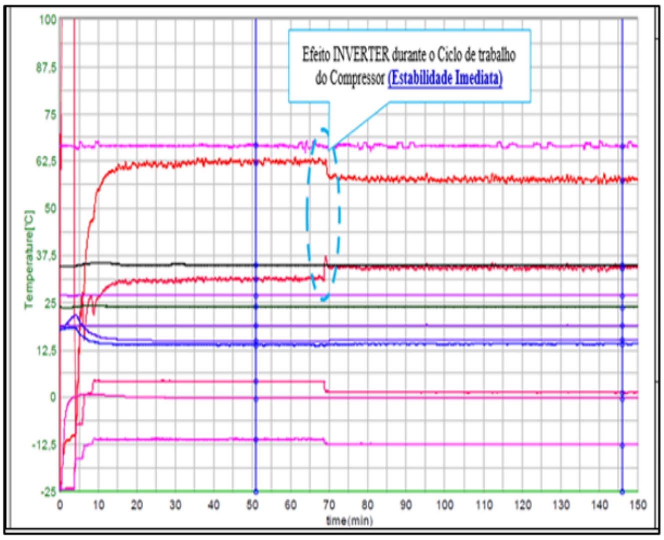
MEASURING ITEM		CUR 1	CUR 2
Capacity	Btu/h	8767,9	9144,9
ERR	Btu/hW	9,561	10,224
Power Input	W	917,0	894,5
Air Flow (Lev)	m³/min	6,95	7,41
Current	A	4,18	4,08
Voltage	V	220,6	220,1
ID Air DB (Ent)	°C	26,71	26,69
ID Air WB (Ent)	°C	19,41	19,38
ID Air DB (Lev)	°C	14,32	14,41
ID Air WB (Lev)	°C	13,28	13,38
OD Air DB	°C	35,01	35,00
OD Air WB	°C	23,91	23,89
Pressure 1	kg/cm²	0,00	0,00
Pressure 2	kg/cm²	0,00	0,00

Figure 7: AS09UBTXAZ model test result (on/off) and Table 5 result.
Source: Authors, (2023).

Tabela 4: Psychrometric Calorimeter Data Sheet (Inverter)_after.

Psychimetric Calorimeter Data Sheet *(Inverter)*					
RAC TIPO ON/OFF	**Model**		AR09BVFAAA		
	Manufacturer		Wind Free		
	Type		Cooling		
	REFRIGERANT CHARGE (gram)		500g (R410A)		
	Condition		Cooling steady state		
	Supply voltage (v)		AC 220v		
	CAPACITY (Btu/h)		9000		
	Power(w)		1000 WATT		
	Current (amp)		4,8 (A)		
MEASURING DATA		Data	MEASURING DATA		Data
Capacity	Btu/h	9299,1	Static Pressure	mmAq	-0,02
ERR	Btu/Hw	9,469	Nozzle Diff Pressure	mmAq	69,18
Power Input	W	1045,4	Air Flow (Lev)	m³/min	9,86
Current	A	4,96	Heat Leakage	Btu/h	232,8
Voltage	V	219,6	Draun Weight	kg/h	0,64
Power Factor	%	96,00	Latent Heat	Btu/h	1501,9
Capacity Ratio	%	109,99	Sensible Heat	Btu/h	8397,2
Power Input Ratio	%	104,54	Sensible Heat Ratio	%	84,83
Current Ratio	%	103,29	Barometric Pressure	mmHg	760,0
ERR Ratio	%	105,21	Nozzle IO 75/75/80/100		-/-/O/-

Source:Authors, (2023).



MEASURING ITEM		CUR 1	CUR 2
Capacity	Btu/h	10455,9	9865,4
ERR	Btu/hW	8,990	9,459
Power Input	W	1163,0	1043,0
Air Flow (Lev)	m³/min	9,85	9,84
Current	A	5,49	4,96
Voltage	V	220,2	219,1
ID Air DB (Ent)	°C	27,00	27,00
ID Air WB (Ent)	°C	19,02	19,00
ID Air DB (Lev)	°C	14,86	15,27
ID Air WB (Lev)	°C	13,82	14,10
OD Air DB	°C	35,03	35,06
OD Air WB	°C	24,01	23,96
Pressure 1	kg/cm²	0,00	0,00
Pressure 2	kg/cm²	0,00	0,00

Figure 8: Test result of model AR09BVFAAA (Inverter) and Result of Table 6.
Source: Authors, (2023).

Conclusions through Graphic Results

4.3.2.1 Comfort, Consumption and Efficiency (as shown in the Graphs of results in Figures 9 and 10)

- **Comfort**:

Conventional Air Conditioning: Conventional air conditioning can provide thermal comfort, but the room temperature can fluctuate more due to the on/off cycle of the compressor. These fluctuations can cause discomfort, especially in hot and humid weather.

Inverter air conditioning: Inverter air conditioning offers improved thermal comfort due to its variable speed compressor. It can continuously adjust its cooling capacity to match the heat load of the environment, maintaining a more stable temperature and avoiding sudden fluctuations. This results in a more comfortable and pleasant environment.

- **Energy consumption:**

Conventional air conditioning: Conventional air conditioning tends to consume more energy due to the compressor's frequent on/off cycle. Each time the compressor is activated, a power spike occurs. These frequent cycles can increase electricity consumption, particularly in locations where cooling demand fluctuates greatly.

Inverter air conditioning: Inverter air conditioning is more efficient in terms of energy consumption. The variable speed compressor adjusts its rotation speed according to the cooling demand, avoiding energy consumption peaks and maintaining a more continuous operation. This results in lower electricity consumption and energy savings over tim.

- **Energy Efficiency:**

Conventional air conditioning: Conventional air conditioning is generally less energy efficient as it cannot dynamically adjust its cooling capacity. It operates on a fixed duty cycle, which can lead to excessive energy usage when demand is low.

Inverter air conditioning: Inverter air conditioning is known for its energy efficiency. By continuously adjusting the cooling capacity according to demand, the inverter compressor avoids wasting energy and operates more efficiently. This results in lower power consumption and greater overall system efficiency. In summary, inverter air conditioning offers greater thermal comfort, lower energy consumption and greater energy efficiency compared to conventional air conditioning. Although the initial cost may be a little higher for the inverter model, the benefits in terms of comfort and energy savings can pay off over time.

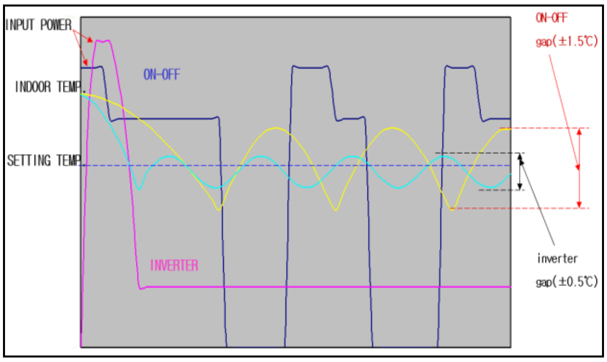


Figure 9: Power and Temperature Result for On/Off and Inverter Air Conditioners.
Source: Authors, (2023).

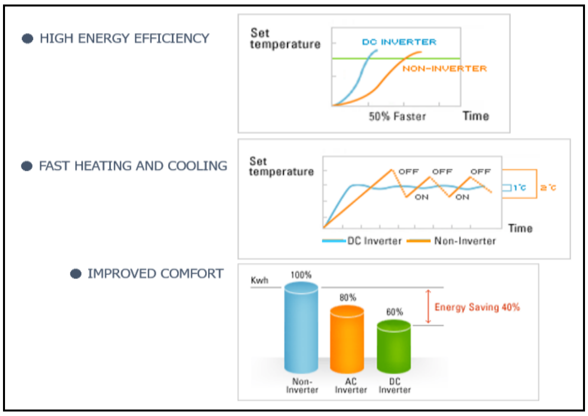


Figure 10: Result of Inverter Air Conditioners 9000 BTUs.
Source: Authors, (2023).

Result in the inverter circuit.

a) Output Result of the Frequency Converter Signal applied to the BLDC compressor.

In the BLDC motor of the compressor, three windings (coils) are used that are positioned at an angle of 120 degrees to each other. The drive's output driver generates alternating electrical pulses to each of these coils, in sequence, creating a rotating magnetic field in the motor. The output signal from the drive's output driver follows a switching pattern known as "120 degrees". It is composed of three control signals (commonly called U, V and W) that alternate in sequence, supplying energy to the motor windings.

The basic principle is that, at a given instant of time, one of the signals is turned on while the other two are turned off. This creates a magnetic field that pulls the motor rotor into a certain position. Then the signals are switched so that another pair of coils is active, and so on. This 120-degree switching sequence allows the BLDC motor to rotate smoothly and perform well.

The frequency inverter output driver controls the switching on and off time of these signals according to the desired rotation speed for the compressor. This is done by adjusting the duty cycle of the PWM signals, which determine the amount of energy supplied to each coil and therefore the power and speed of the motor, as shown in the block diagram of the inverter circuit in the Outdoor unit (Figure 11). It is important to note that the 120 degree switching pattern is only one of the possible control strategies for BLDC motors and may vary depending on the design and manufacturer of the inverter air conditioner.

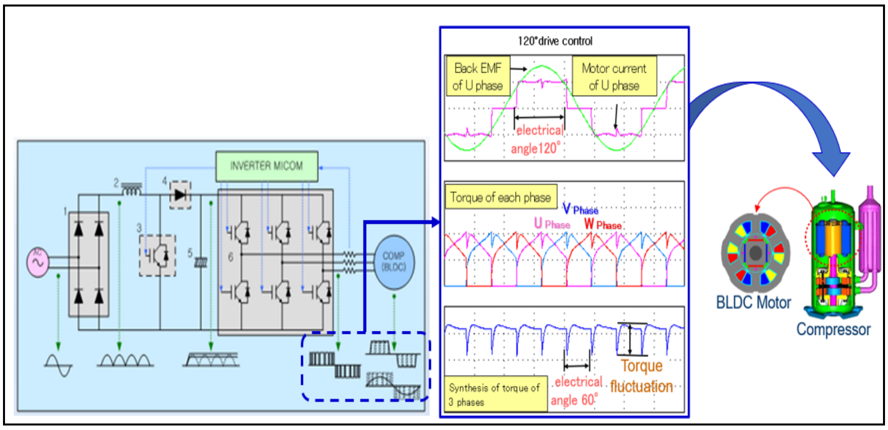


Figure 11: Signal Output Result applied to the BLDC compressor.
Source: Authors, (2023).

Result of Energy Efficiency and the environment in air conditioners with Inverter technology in Brazil.

Introduction of New, more modern Inverter Air Conditioning models (NPI)

New latest generation Inverter air conditioning models (Improvements Applied): The latest generation Inverter air conditioning systems offer several improvements in relation to previous models. Here are some common features found on more advanced inverter air conditioners:

• Improved energy efficiency: The latest generation inverter air conditioners are designed to offer greater energy efficiency. They continuously adjust the compressor speed according to the cooling demand, resulting in a more efficient use of energy compared to conventional models.

1. Inverter air conditioning systems can be rated for energy efficiency using the Seasonal Cooling Performance Index (IDRS). The IDRS is a metric that takes into account the performance of the air conditioner in different operating conditions, reflecting its performance throughout the year. In Brazil, for example, the Brazilian Labeling Program (PBE) of the National Institute of Metrology, Quality and Technology (INMETRO) uses the Energy Efficiency Index (IEE) as the energy efficiency metric for air conditioners, not the IDRS. The IEE takes into account factors such as compressor, fan and condenser efficiency. Therefore, when looking for inverter air conditioners with high energy efficiency, it is recommended to check the energy rating labels and technical specifications of the models available on the market, observing the specific efficiency metrics adopted by the reference country.

2. By Inmetro through Ordinance No. 234, of June 2020: With the improvement of the Brazilian Labeling Program (PBE) for air conditioners. The changes will tighten the criteria for classifying equipment as A – those with the lowest electricity consumption – and will show the savings of appliances with a variable speed compressor (inverter).

With the new ordinance, the methodology for calculating energy efficiency is now done using the partial load method and seasonal metrics.

The PBE is a program through which the performance of products is attested considering criteria of energy efficiency, noise, use of natural resources, among others. In the case of air conditioners, the main test item is energy efficiency for air cooling, with equipment classified from 'A', for those that consume less energy, to 'D' for equipment that consumes more energy. . The ENCE (National Energy Consumption Label) is the seal of conformity that demonstrates that the product complies with the requirements established in the PBE and informs the consumer of relevant aspects for making a purchase decision, including energy consumption or classification in terms of performance.

3. By Inmetro through Ordinance No. 234, of June 2020. According to art. 4, as of December 31, 2025, national and imported manufacturers must manufacture or import, for the national market, only split-type air conditioners in compliance with the energy efficiency classes established in Table 5 for air conditioners, as partial improvement contained in the annex to the ordinance.

Table 5: Energy efficiency class for Split air conditioners with suitability period for manufacture and import (NR).

split air conditioners (With deadline for suitability for manufacture and import until 31/12/2025)	
Classes	**Seasonal Cooling Performance Index – IDRS (Wh/Wh)**
A	≥7,00
B	≥6,00
C	≥5,30
D	≥4,60

E	≥3,90
F	≥3,50

Source: [18].

- **More accurate temperature control:** Modern inverter air conditioners are able to maintain a more stable and accurate temperature in the room. They respond quickly to temperature variations, adjusting the cooling capacity more precisely, which provides respectively improved thermal comfort.

➢ From this topic onwards, we will choose the **Wind Free Inverter** Air Conditioner as an example.

➢ The Inverter Wind Free air conditioning model is a technology developed to provide more comfortable and efficient cooling, with a reduction in direct air currents. The distinctive feature of Inverter Wind Free air conditioning is the "Wind Free" mode, which seeks to minimize the sensation of direct cold air, creating a softer and more pleasant environment. They utilize a series of micro holes in the indoor unit to widely disperse air, preventing direct wind gusts, this results in greater energy efficiency and energy savings compared to conventional models, as the compressor does not need to turn on and off. turn off frequently. See Figure 12.

➢ Inverter Wind Free air conditioners can also offer additional function features such as high-quality air filtration, smart remote control, integration with voice assistants and Wi-Fi connectivity for remote control and monitoring. See below some definitions of some Advanced functions of the Wind Free reverse air conditioner.

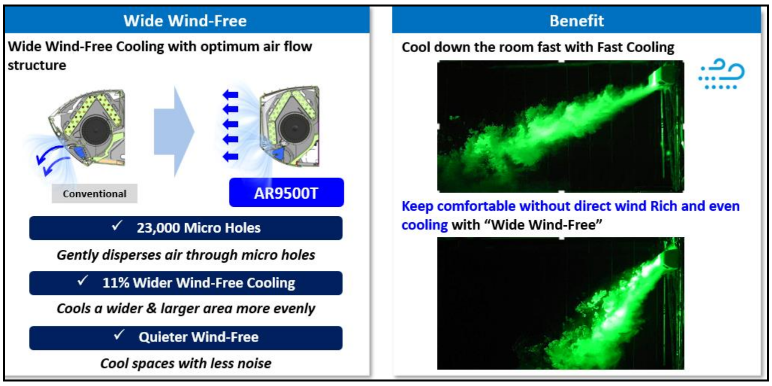


Figure 12: Technological strategy for Inverter Wind-Free Air Conditioning.
Source: Authors, (2023).

- **Fast Cooling:** Cools the environment faster from end to end. Designed for wider and farther cooling
- **Wide Wind-Free**: Stay comfortably refreshing in an environment without feeling cold.
- **AI Auto Cooling**: Advanced Wind-Free AI Auto Cooling considering fast cooling, healthy humidity & comfort cooling. Analyzing my preferred mode & room condition, automatically switches to the most appropriate mode.
- **Tri-Care Filter**: A Zeolite Coating Filter helps to collect fine dust, as well as inactive bacteria, viruses and allergens (99% Anti-Bacteria, PM10 Reduction, 99% Anti-Virus and 98% Anti-Allergy).

- **Eco-friendly refrigerant gas:** Modern Inverter air conditioners are being designed using more eco-friendly refrigerant gases, such as R-32, which have less global warming potential and less environmental impact compared to older refrigerant gases, such as R-410A. It follows the main differences between the two gases and some tables explaining Global Warming Potential values.
  - The main differences between R32 and R410A:

1. R410A (introduced in 2006) is the most widely used refrigerant today. However, the constant search for better fluids in terms of environmental impact leads us to present R32 to the world.
2. R32 is a 100% pure refrigerant. Therefore, its recycling and reuse becomes quite easy. Ironically, R410A is a mixture of R32 and R125. Being a mixture, it is no longer so easy to recycle or reuse. Both fluids have zero impact on the ozone layer, but the impact on global warming or Global Warming Potential (GWP) is 1/3 of R410A. We will show the main values for 100 years of warming potential as shown. R32 is more energy efficient than R410A, requires less refrigerant volume per kW, that is, it has a much lower density, which requires less refrigerant as shown in Figure 13.

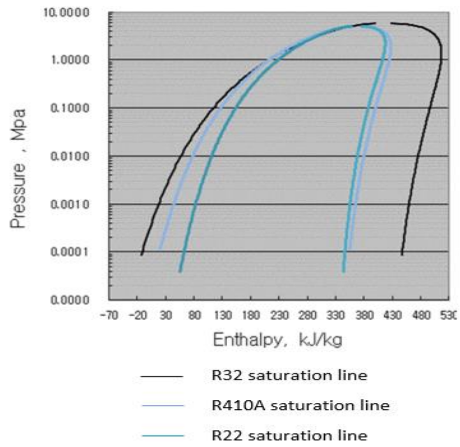


Figure 13: Comparison of R410A X R32 Refrigerant Charges.
Source: Authors, (2023).

4. R410A is not a flammable fluid. R32 is a low flammability and toxicity fluid, class 2L. R410A is class 1 L, non-flammable. It is a classification of ASHRAE34 and IS0817. ISO 817 and ASHRAE 34 define R32 as a slightly flammable gas. See Table 6.

Table 6: Safety Regulations for Refrigerant Gas R32.

	International	Europe	America
Classification	ISO 817	←	ASHRAE 34
Restriction of use for security	ISO 5149	EN378	ASHRAE 15
	IEC60335-2-40	EN60335-2-40	UL207, 250, UL471, 474, 484, UL 984, 1995

Source: Authors, (2023).

5. R32 has a better volumetric capacity than R410, this can result in smaller refrigerant piping size, smaller diameters, increasing efficiency.
6. Like all refrigerant gas, we have to take some precautions to add R32 in an air conditioning process, which are:
- Be very careful not to overload the system. If you use a pipe longer than specified in the manual, you will need to add more refrigerant for each additional meter, balancing the system.
- STAY PROTECTED by adding R-32 with the help of a digital scale.
- If more than 100% of the amount of R32 is placed, it is not easy to judge the proper charge value. Low pressure and current are very similar after charging 100 ~ 250% of the amount.

V. CONCLUSION

We can conclude that inverter air conditioning has a lower daily consumption of electricity mainly due to the lower temperature difference that occurs in the heat exchangers between the refrigerant fluid and the other medium, contributing to the well-being of world society. As a result, the average COP (function of performance coefficient) of an inverter air conditioner is higher than that of a non-inverter. The magnitude of the increase in energy efficiency is strongly influenced by the thermal load profile of the conditioned environment. The research also indicates a certain scarcity of works related to the theme, since most of the works rejected during the analysis only considered the thermal comfort of the user, without mentioning whether the created application generated an increase in energy efficiency and modern functions applied in inverter technology (Example: Inverter Wind-Free Air Conditioning). It is ideal to check which system is best suited to the characteristics of the project, analyzing the size, thermal load, type of ecological gas and purpose of the plant, among other technological factors as explained in this research. Also, we can observe that the components and circuits with inverter technology are more modern, economical and silent. Therefore, traditional devices have become cheaper. Inverter technology was developed for electrical and electronic appliances, such as air conditioners, refrigerators, freezers, washing machines and stoves. With the aim of reducing energy consumption through a different type of motorization. Unlike traditional compressors, which turn on and off during operation, when they start to cool the environment or the interior, inverter motors never turn off completely. By avoiding spikes in electricity consumption, they work more efficiently and have less of an impact on your electricity bill. With a system that practically manages voltage jumps, the Inverter's great advantage is energy savings, which can reach up to 70%. Still regarding the operation of the compressor, the ambient temperature remains stable, as there are no oscillations in its operation. This is because the device does not turn on and off during air conditioning, reducing the generation of noise.

VI. Acknowledgments:

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