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Comparative analysis of energy-efficient air conditioner based on brand

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Abstract

The availability of numerous air conditioners in the market with various brands and types often leads consumers to be unaware that the purchased air conditioner may be inefficient in terms of energy usage. This research aims to determine the most energy-efficient air conditioner based on the brand of air conditioners available in the market. The research method consists of four stages: data collection, data preprocessing, data analysis, and interpretation of results and conclusions. The data used in this study was obtained from the database of the Directorate General of New, Renewable, and Energy Conservation (EBETKE), which consists of 11 AC brands sold in the market. Data analysis was performed using data distribution analysis techniques, standard deviation calculations, and correlation analysis between variables, such as the Pearson's correlation coefficient. The results of this study show that the AC brand with the highest average efficiency value is Mitsubishi Electric, with a value of 16.36 Energy Efficiency Ratio (EER), while the AC brand with the lowest average efficiency value is GREE, with a value of 5.640 (EER). Each AC brand has a different average efficiency value, with significant variations. From the correlation heatmap results, the AC power does not appear to significantly affect the AC efficiency value, where AC with lower power tends to have higher efficiency values, but there are also AC with high power and high efficiency values. Additionally, the cooling capacity value also appears to have a small effect on the AC efficiency value, where AC with lower cooling capacity tends to have higher efficiency values. However, some AC brands have high cooling capacity values but also have high efficiency values. This study also shows a moderate correlation between the AC efficiency value and the AC's annual energy consumption value, where AC with higher efficiency values tends to have lower annual energy consumption values.

Keywords:
Comparison, AC, energy efficiency, brand.

1 Introduction

The increase in energy consumption for Air Conditioning (AC) worldwide has become one of the main factors contributing to the rise in energy demand. According to the prediction of the International Energy Agency (IEA), the energy consumption for AC is expected to contribute approximately 35% to the growth in energy demand by 2050, particularly in Southeast Asia including Indonesia [1]. Inefficient use of ACs leads to a significant increase in electricity costs for households and has negative impacts on the environment. The wide range of ACs available in the market with different brands and types causes consumers to overlook the energy efficiency aspect when purchasing an AC. The Directorate General of New, Renewable Energy, and Energy Conservation (EBTKE) in Indonesia has introduced an energy labeling system for ACs. This system aims to assist consumers in choosing efficient ACs and provide transparent information on the energy efficiency level of every AC sold in the market [2]. The system is based on several variables, including power, cooling capacity, efficiency, annual electricity consumption, and electricity cost. Through the energy labeling system provided by the Directorate General of EBTKE, Indonesian consumers can more easily choose efficient ACs. However, many consumers still prioritize price and brand over energy efficiency when buying ACs, according to studies[3],[4]. Another study conducted by Wang et al. showed that consumers in China tend to purchase larger and more expensive but less energy-efficient ACs. Therefore, it is crucial to enhance consumers' understanding of the importance of selecting energy-efficient ACs and provide transparent information on the energy efficiency level of every AC sold in the market [5]

Various studies have been conducted on the comparative analysis of energy-efficient ACs. For instance, a study collecting data from various types of ACs, including split, portable, and central ACs, showed that split ACs have better energy efficiency compared to other types [6]. Additionally, a study on the energy efficiency performance and indoor air quality of split ACs with different Seasonal Energy Efficiency Ratio (SEER) was conducted, collecting data on energy, cooling performance, and indoor air quality of two different types of split ACs. The study results indicated that split ACs with a higher SEER have better energy efficiency but also require higher costs[7]. Another study conducted in the climate of Saudi Arabia compared the energy efficiency of various types of AC systems by considering energy consumption and system performance of four different types of ACs. The study results showed that ACs with automatic temperature control and inverter technology had better energy efficiency [8]. Comparing variables such as power, cooling capacity, annual energy consumption, electricity cost, and efficiency of various AC brands will provide transparent information on the available AC efficiency in the market. This is crucial to reduce the impact of excessive energy consumption and save high electricity costs, thus assisting users in choosing the most efficient and environmentally friendly ACs.

This study aims to compare the efficiency of ACs based on the brands available in the market. The data used in this research is energy-saving labeled inverter AC data obtained from the database of the Directorate General of New, Renewable Energy, and Energy Conservation (EBTKE). The research data consists of various AC brands available in Indonesia, including brand, power, cooling capacity, annual energy consumption, electricity cost, and efficiency.

2 Research Method

This study aims to determine the most energy-efficient AC based on AC brand sold in the market using Python programming language and run on Google Colab. To simplify the research process, research steps were created as shown in Fig. 1.

2.1 Data Collection

The research data was obtained from the database of the Directorate General of New, Renewable, and Energy Conservation (EBETKE). The data used in this study consists of various AC brands available in the market, and the data obtained from this database is tailored to the research needs, such as brand, power, cooling capacity, efficiency, annual energy consumption, and electricity costs. With the AC usage time of 8 hours per day and a cost of Rp 605/kWh, the calculation can be made based on the Eq. 1-5.

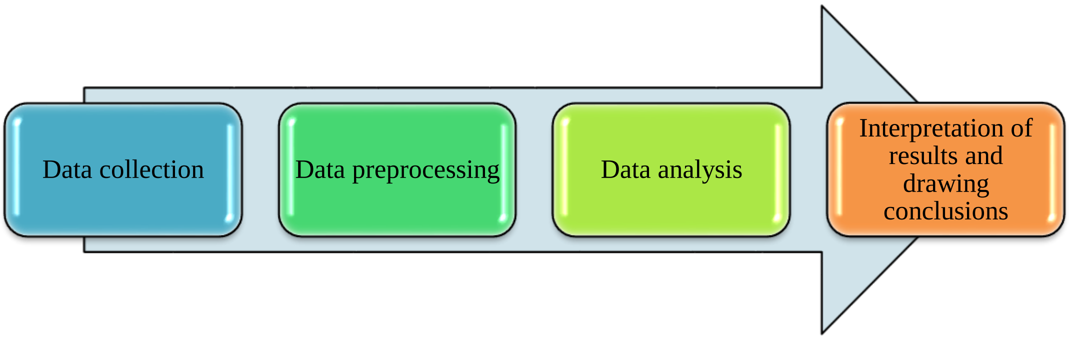

Fig. 1. Research stages.

$$P = \frac{W}{t} \quad (1)$$

Where P represents power, W represents energy, and t represents time.

$$E_{annual} = \frac{P\ X\ 8\ Hours\ X\ 365\ days}{1000} \quad (2)$$

Where E_{annual} represents annual energy consumption, P represents power, 8 hours represents the number of hours of AC usage, and 365 days represents the number of days in a year.

$$C = E_{annual} X\ E_{price} \quad (3)$$

Where C represents electricity cost, E_{annual} represents annual energy consumption, and E_{price} represents the price of electricity per kilowatt-hour.

$$\eta = \frac{CC}{P} \quad (4)$$

Where η represents efficiency, CC represents cooling capacity, and P represents power.

$$EER = \frac{Qc}{P} \quad (5)$$

Where EER represents the energy efficiency ratio, Qc represents the cooling capacity of the AC unit, and P represents the power consumption of the AC unit.

2.2 Data Preprocessing

This stage is a data processing step prior to analysis. Data preprocessing includes data cleaning, data transformation, and filling missing data [9]. Data obtained from the EBETKE database is normalized, which is the process of converting the number of units for each brand of AC to the same amount. The purpose of data normalization is to prevent the analysis results of AC efficiency from being dominated by brands with a larger number of units. Data preprocessing is an important stage in the data analysis process, as well-processed data will facilitate subsequent processes and produce more accurate results.

2.3 Data Analysis

In this stage, several methods can be used to explore and process the data for better understanding. The data is analyzed using the Python programming language, which allows for analysis such as distribution analysis to observe how the data is spread within a population. Furthermore, the standard deviation is calculated to determine the variation of AC efficiency among each brand. The standard deviation can be calculated using the Eq. 6.

$$s = \sqrt{\frac{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}{n(n-1)}} \quad (6)$$

Where s is the standard deviation of the sample, x_i is the value of each data in the sample, $\bar{x}$ is the mean of all the data in the sample, and n is the number of data in the sample [10]. Correlation analysis between variables is also carried out to determine the relationship between two or more variables[11].The technique commonly used for correlation analysis between variables is Pearson's correlation coefficient, which can be calculated using the Eq. 7.

$$r_{xy} = \frac{\sum xy}{(n-1)S_x\, S_y} \quad (7)$$

Where r_{xy} is the Pearson correlation coefficient, $\sum xy$ is the sum of the products of x and y, n is the sample size, x is the independent variable, y is the dependent variable, and S is the standard deviation. The value of the correlation coefficient ranges from -1 to 1. A value of -1 indicates a strong negative correlation between the two variables, 0 indicates no correlation, and 1 indicates a strong positive correlation [12]

2.4 Interpretation of Results and Conclusion Drawing

This stage is where the analysis results are interpreted and conclusions are drawn in accordance with the research objectives.

3 Results and Discussion

The data obtained from the EBETKE database are energy-efficient labeled inverter AC data consisting of various brands. Inverter and non-inverter ACs differ in compressor rotation control and electricity usage. Non-inverter ACs have a compressor that only functions at one speed, either on at full speed or off. When the room temperature reaches the desired temperature, the compressor will turn off, and when the room temperature rises again, the compressor will turn on again at full speed [13][8]In inverter ACs, the compressor speed can be adjusted according to the cooling needs of the room. When the room temperature has reached the desired temperature, the compressor speed will decrease and work at a lower speed, thus reducing electricity consumption. In addition, inverter ACs also have the ability to regulate room temperature more accurately and stable, making electricity usage more efficient. The energy-efficient labeled inverter AC data used in this study consists of 6 variables such as brand, power, cooling capacity, efficiency, annual energy consumption, and electricity cost.

3.1 Preprocessing Data

Data preprocessing is an important stage in the data analysis process, because well-processed data will facilitate the next process and produce more accurate results. The data obtained from the EBETKE database undergoes data normalization, which is the process of converting the number of units for each brand of AC to the same amount. The purpose of this data normalization is to prevent the efficiency analysis results of AC from being dominated by AC brands with more units. The original database has uneven numbers of AC units for each brand of AC, therefore it is necessary to normalize each brand of AC to have the same number of units. The number of AC units for each brand is 10 units, with 11 different AC brands as seen in Fig. 2, where the amount of data used for the analysis of energy-efficient AC efficiency comparison is 110 data.

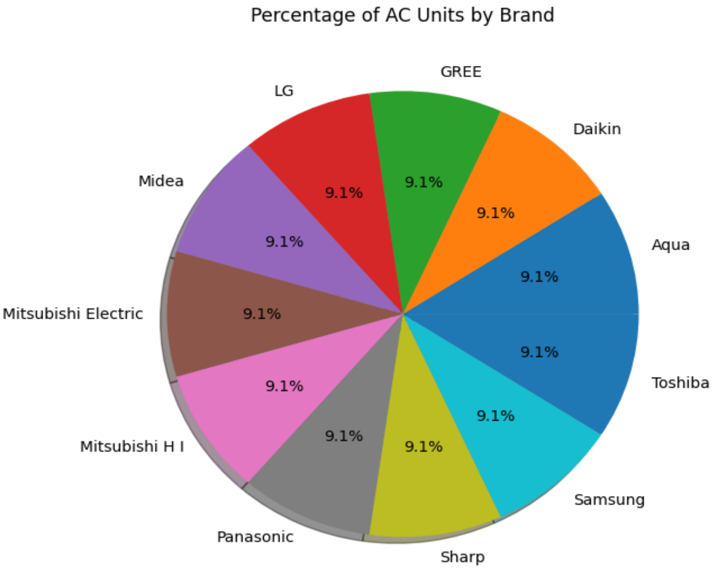

Fig. 2. Percentage of AC units in the dataset.

3.2 Data Analysis

After determining the number of AC units for each brand, the next step is to calculate the average efficiency values of each AC unit and their standard deviations, as shown in Fig. 3.

The visualization results using the bar chart indicate that the efficiency values of AC units from each brand have diverse distributions. However, to gain a clearer understanding of the efficiency comparison based on brand, it is necessary to calculate the average efficiency values of each AC unit. The research findings reveal that the Daikin brand achieves the highest efficiency with an Energy Efficiency Ratio (EER) of 16.36, while the GREE brand has the lowest efficiency with an EER ratio of 5.83. According to the EER standards in the United States, a good EER value ranges from 10.5 to 14, depending on the type and capacity of the AC unit [14]The difference in efficiency among various AC brands is influenced by several factors such as technological design. The differences in technological design between Daikin and GREE ACs can impact their performance efficiency. Each brand implements different design approaches to optimize energy efficiency. This includes the use of more efficient components, inverter technology, improved insulation materials, and enhanced temperature and humidity control [15]. The quality of components used in AC units also affects efficiency. Brands that utilize high-quality and tested components tend to have more efficient performance [16]. The variation in component selection and quality between Daikin and GREE can influence their ability to achieve high levels of efficiency. Furthermore, differences in construction and manufacturing quality between AC brands can affect overall performance and efficiency. Brands that maintain high standards in construction quality, product testing, and production quality control tend to produce more efficient AC units [17]. Additionally, in this stage, the calculation of standard deviation for efficiency values is also performed. The standard deviation value indicates the extent of variation in efficiency values from their mean. A smaller standard deviation implies that the efficiency values of AC units are closer to each other, suggesting similarity in efficiency. Conversely, a larger standard deviation implies greater variation among efficiency values, indicating differences in efficiency. Standard Deviation (SD) is a measure of variability or how spread out data is from its mean value [18].The obtained results for standard deviation show that the Aqua brand has a standard deviation value of 1.35, indicating that the efficiency values of Aqua AC units are relatively close to their mean efficiency value of 12.26. This indicates that the efficiency levels of each Aqua AC unit are relatively uniform. On the other hand, the Mitsubishi Electric brand has a standard deviation value of 2.22, indicating that the efficiency values of Mitsubishi Electric AC units are more spread out from their mean efficiency value of 15.35. This suggests that the efficiency levels of each Mitsubishi Electric AC unit are less uniform, similar to the Daikin brand.

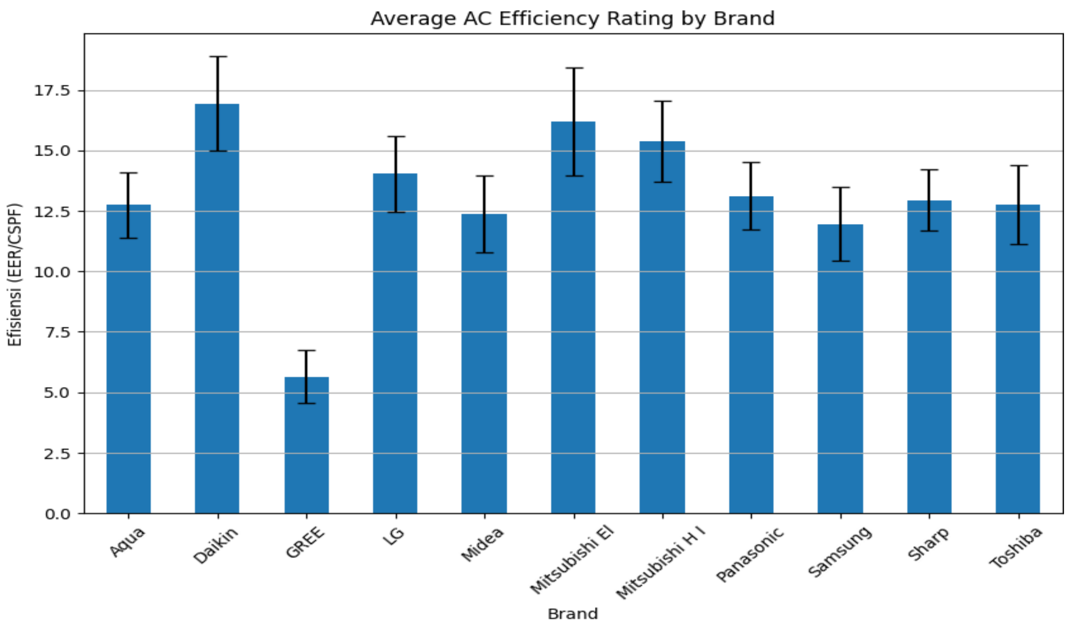

Fig. 3. Bar chart for visualizing the distribution of AC efficiency values.

The correlation analysis between efficiency and variables such as power, cooling capacity, efficiency, annual energy consumption, and electricity cost were calculated and visualized using a correlation heatmap. A correlation heatmap is a diagram that illustrates the linear relationship between two or more variables using colors as a substitute for numerical values [19]. The equation used in the correlation heatmap is the Pearson correlation equation. This equation measures the level of linear correlation between two variables by calculating the Pearson correlation coefficient (r). The value of r ranges from -1 to 1, where -1 indicates a strong negative correlation, 0 indicates no correlation, and 1 indicates a strong positive correlation [20]. The visualization results with the correlation heatmap can be seen in Fig. 4, where red color indicates strong positive correlation while blue color indicates strong negative correlation. Based on the data in this study, the correlation heatmap shows that efficiency has a small positive correlation with annual energy consumption of 0.2 and power of 0.014, and a small negative correlation with cooling capacity, while the electricity cost variable does not appear on the correlation heatmap, indicating no correlation between AC efficiency and electricity cost. It should be noted that this only applies to the dataset used in this study, so it may not necessarily apply to other data.

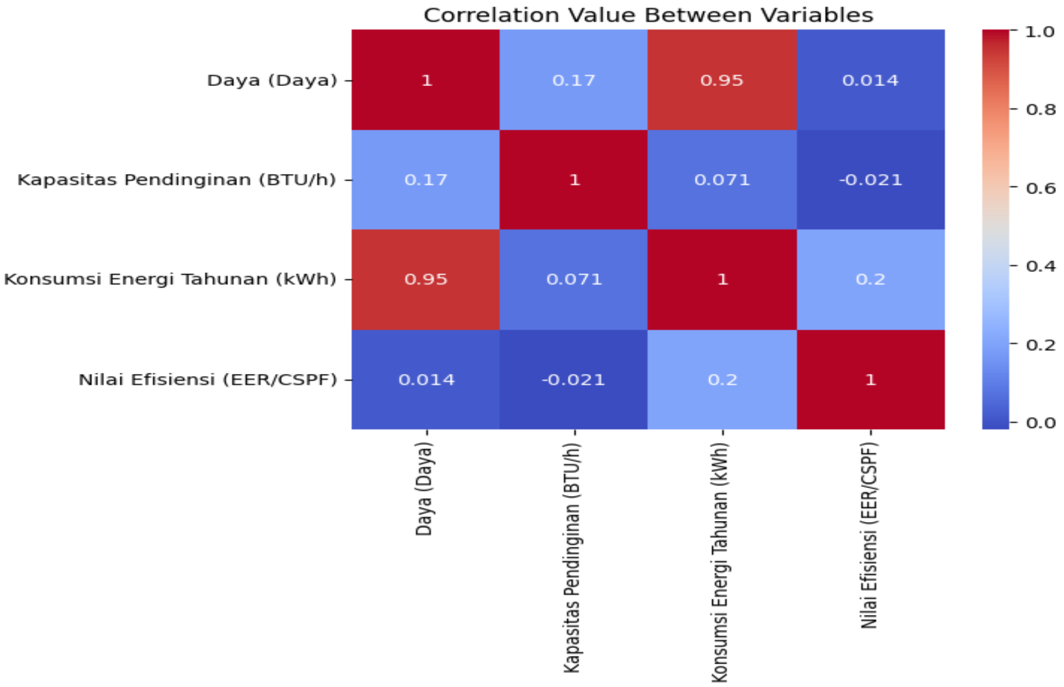

Fig. 4. Result of visualization using correlation heatmap.

The average efficiency values of each AC and power are compared using a bar chart to see the comparison of these variables more clearly. Based on the results obtained, it can be seen that there is no strong correlation between efficiency level and power in ACs of various brands. For example, Aqua brand has a relatively high efficiency level (12.744) but also has a relatively high power (1205.180), while Midea brand has a relatively high efficiency level (12.357) but has higher power compared to other brands (2195.540). In addition, there are also some brands such as GREE that have low efficiency level (5.640) but have high power compared to LG brand. This shows that there is no strong relationship between efficiency level and power in ACs of various brands as seen in Fig. 5. However, it is not impossible that other factors such as technology used, AC type, and data quality can also affect the efficiency and power level of ACs.

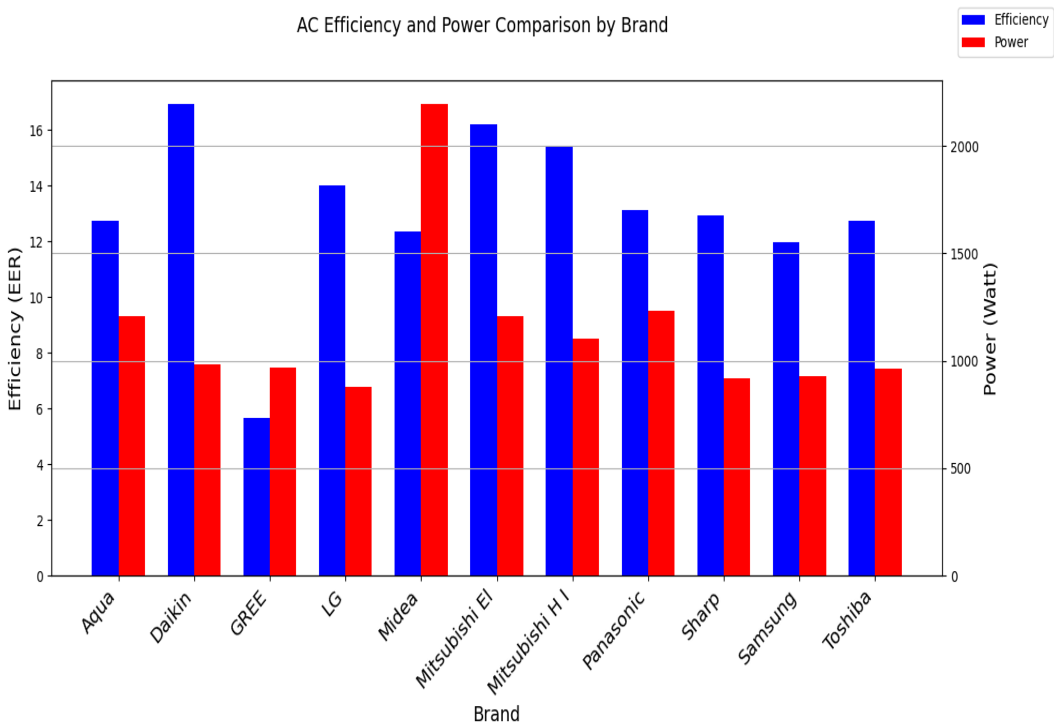

Fig. 5. The relationship between efficiency and power.

Similar to power, the obtained average values of AC efficiency and cooling capacity indicate that there is no clear correlation between these two variables. For example, an AC brand with high efficiency, such as Daikin, does not always have a high cooling capacity, and conversely, an AC brand with high cooling capacity, such as Panasonic, does not always have high efficiency, as shown in Fig. 6.

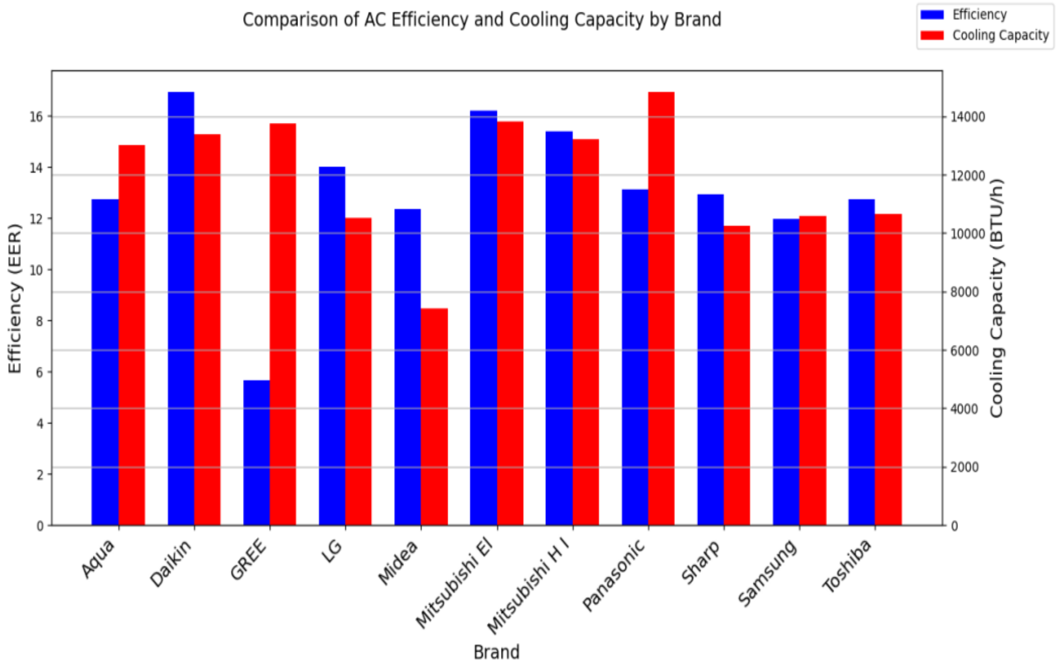

Fig. 6. Relationship between efficiency and cooling capacity.

The visualization of the average efficiency and annual energy consumption values can be seen in Fig. 7, where the Mitsubishi Electric AC brand has a high efficiency value of 16.200, but its annual energy consumption is higher than Mitsubishi H I, which has a lower efficiency value of 15.392. On the other hand, Daikin has high efficiency and low annual energy consumption. The line plot shows that there is no strong correlation between the efficiency level and annual energy consumption of various AC brands.

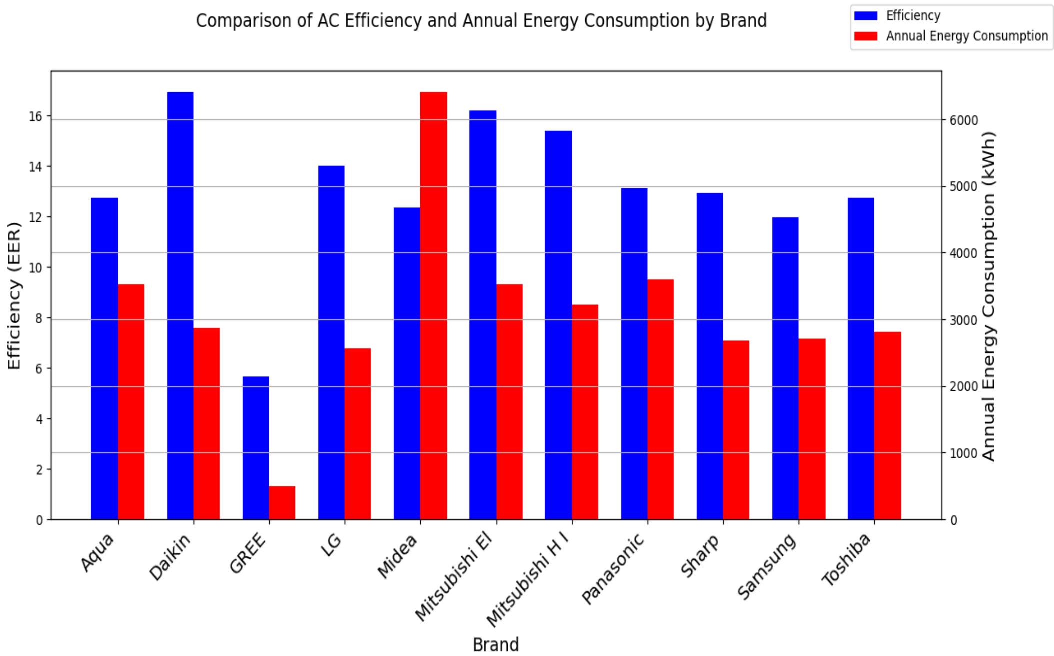

Fig. 7. Relationship between efficiency and annual electricity consumption.

Based on the visualization results of efficiency and electricity consumption, it can be concluded that not all air conditioners with high efficiency have low electricity costs. For example, Mitsubishi Electric has higher efficiency compared to Mitsubishi H I, but Mitsubishi H I has lower electricity costs than, Mitsubishi Electric, as shown in Fig. 8. It is important to note that other factors such as technology used, AC type, and data quality can also affect the efficiency level and electricity cost.

4 Conclusion

Based on the analysis of energy-efficient labeled AC data, it can be concluded that the analysis was performed using Python for visualization with bar charts, correlation heatmaps, and calculation of average values and standard deviations for each AC brand. The analysis results showed that each AC brand with the same number of units has varying efficiency values, and there is a significant difference between the average efficiency, power, cooling capacity, and annual energy consumption values of each AC brand. The AC brand with the highest average efficiency value is Daikin, Mitsubishi Electric, and Mitsubishi H I, while the brand with the lowest average efficiency value is GREE. Furthermore, it is also observed that AC brands with high average power, cooling capacity, and annual energy consumption values do not always have high average efficiency values, and vice versa. This indicates that factors other than efficiency also affect the power, cooling capacity, and annual energy consumption of an AC. However, in general, it can be concluded that AC brands with high average efficiency values have greater potential to save electricity costs and are a better choice compared to other brands.

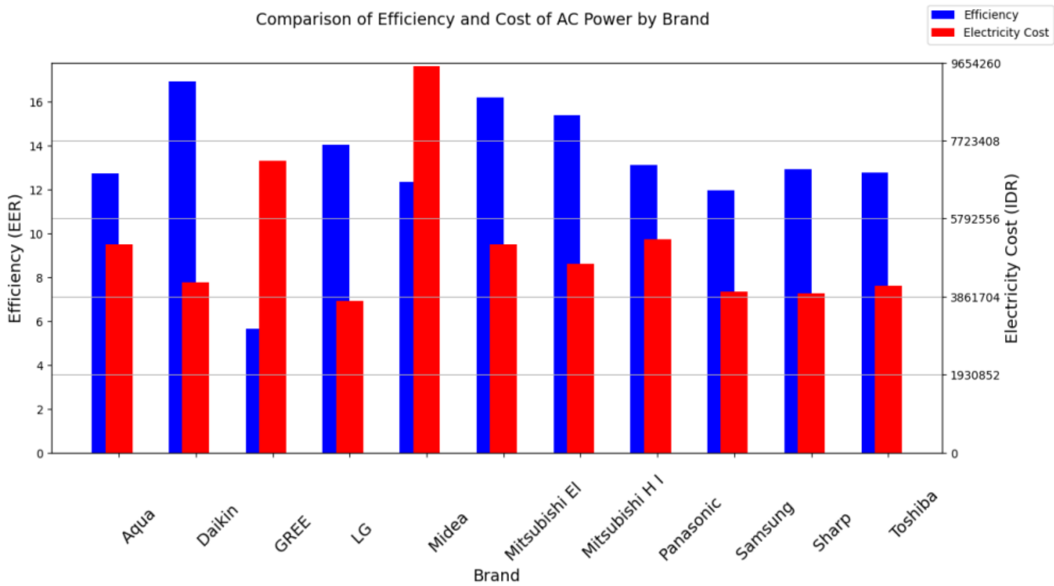

Fig. 8. Relationship between efficiency and electricity cost.

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