Economics-Based Payback and Life Cycle Cost Savings Assessment of Inverter Type Air Conditioners

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Abstract. This paper investigates the options for a consumer to choose between different inverter and non-inverter type residential air conditioners (ACs) concerning their payback periods (PPs) and Life Cycle Cost (LCC) savings. The economics-based analysis carried out to evaluate the PPs by which the costs associated with owning and operating 3-star, 4-star, and 5-star inverter AC models are recoverable compared to non-inverter type (baseline model). The product costs (C_p), the repair costs (C_R), the maintenance costs (C_M), and the energy costs (C_E) are taken as the decision parameters for evaluating the payback periods (PPs). It is shown that PP strongly depends on the energy cost. Estimates of PPs are calculated as the future value of present cost involved in buying, maintaining, and running the ACs. It is concluded that inverter technology can save electrical energy by 12-22.4% compared to a non-inverter air conditioner. PPs of 3-star inverter AC is estimated 2.17 years while PPs of 4-star and 5-star inverter ACs are 2.42 years and 2.33 years for 10 hours operation in a day when a higher slab of unit energy cost is considered. Depending on PP and daily usage requirements, a consumer can choose either a less efficient AC priced at a lower initial cost but more running cost or a more efficient AC priced at a higher initial cost but lesser running cost.

Keywords. Inverter AC, life cycle cost, payback period

1. Introduction
New Delhi, India has a composite climate i.e., very hot-dry climate in summer (from April to June) and hot-humid climate in the rainy season (from July to September). Therefore, to counterbalance these extreme climatic situations, most people are switching over to own and use air conditioners (ACs). However, the high running cost of air conditioner is significant concern for consumers in general. To cut the electricity bills, they look for higher energy-efficient air conditioners.

The energy efficiency and performance of refrigeration cycle can be improved to a great extent by employing variable speed technology [1]. Ha & Jeong showed that a variable speed compressor contributed 21% reduction of the annual power consumption over a fixed speed compressor [2]. Huge electricity savings were obtained by replacing less energy efficient (e.g., 1- star ratings) air conditioners with more energy-efficient inverter ACs incorporating a variable frequency compressor [3].

Energy Efficiency Rating (EER) of the compressor was found to have much effect on system performance and economics [4]. In comparison to a base-case, a noticeable reduction in energy cost was obtained by investing more in equipment, primarily improving its electric motor, evaporator, and compressor [5]. Higher the cooling loads, the more was the product cost per unit of cooling capacity, while the energy cost per unit cooling load was decreased [6]. It was demonstrated that a higher value on more efficient components is justified when the electricity price is high [7]. Optimizing the energy
savings require a variable-speed compressor's cost not to exceed 26% than that of a fixed speed compressor. When the aim is to optimize the cost savings, a variable-speed compressor could be justified for its price, not exceeding 20% than that of a fixed speed compressor [8].

The effects of energy reduction using the inverter air conditioner are mainly attributed to the daily or seasonal changes in the temperature and cooling load. Inverter technology saved energy by 18.3 to 51.7% in different climates. It was shown that the energy savings are enhanced during non-peak summer months and at part load operations.

It is possible to predict the payback period (PP) over the baseline model through economic modelling. Accordingly, a consumer can assess the cost-benefit through efficiency enhancement of AC [9].

From the open literature, it is understood that very little information is available on the payback periods (PPs) and life cycle cost savings of inverter ACs over non-inverter ones. The author aims to determine the PPs and life cycle cost savings through economics analysis of inverter ACs with different star ratings against non-inverter AC and investigate the effects of different variables on the PPs.

2. Materials and Methods

Residential air conditioners meet the cooling requirements by employing a vapor compression refrigeration system due to its suitability to almost all types of applications with a wide range of cooling capacities. The input to the vapor compression refrigeration system is in the form of mechanical energy required to run the compressor obtained by an electric motor.

An inverter is a device that can be used to control electric voltage, current, and frequency. The inverter air-conditioner's function is to vary the compressor's power supply frequency to adjust its cooling/heating capacity. The inverter continuously adjusts the compressor speed by changing the frequency to maintain a specific desired room temperature by controlling the refrigerant flow rate. After attaining the preset temperature, the unit annihilates any temperature variations by adjusting its capacity. If the load increases, air-conditioner works at a higher capacity, and if there is a reduction in load, the unit switches to lower capacity.

On the other hand, non-inverter air conditioners operate at a fixed cooling capacity only. The compressor of the non-inverter air-conditioner repeatedly stops and starts to control the indoor temperature.

Energy Star rating is a ready reference to compare and choose from among the best options available. In India, the Bureau of Energy Efficiency develop these ratings. A higher star rating corresponds to the higher energy efficiency of AC. As the cost increase is associated with the technological development of components (mainly compressor) to improve efficiency, the product's cost increases with an increase in its energy efficiency or star rating.

2.1 Mathematical Modelling

Various costs involved in purchasing and operating an air conditioner are product cost ($C_p$), installation cost ($C_{INS}$), repair cost ($C_R$), maintenance/service cost ($C_M$), and energy cost ($C_E$).

Thus, total cost comprises the sum of all the above costs as:

$$C_{Total} = Initial\ Cost\ (IC) + Operating\ Cost\ (OC)$$

where,

$$IC = Product\ Cost\ (C_p) + Installation\ Cost\ (C_{INS})$$

and

$$OC = Energy\ Cost\ (C_E) + Repair\ Cost\ (C_R) + Maintenance\ Cost\ (C_M)$$

$$C_{Total} = C_p + C_{INS} + C_E + C_R + C_M$$

(1)
2.1.1 Product cost ($C_P$). The product cost varies according to the inclusion of some unique features (such as smart eye) or more energy-efficient or both. More efficient products employ components with improved technology, which results in an exponential hike in the product cost. Therefore, a higher star (e.g. 5-star) rated product of the same capacity is costlier than a low star (e.g. 3-star) rated product. Installation cost ($C_{INS}$). Generally, the installation charge is not included in the product cost. For a standard installation, the charge is usually at par irrespective of the air conditioner’s model or brand. Also, as a marketing strategy to attract consumers, manufacturers provide free installation of air conditioners or include this cost in the product price. Therefore, for all selected models of ACs this component ($C_{INS}$) has been excluded in the calculations.

2.1.2 Energy cost ($C_E$). Energy cost is directly proportional to the energy usage (EU) of AC. Unit capacity, energy efficiency ratio (EER) and operating time are the three factors which quantify the energy usage [10] where

\[
EU = \text{Unit capacity} \times \text{operating time} / \text{EER}
\]

The following expression can find the energy cost,

\[
C_R = EU \times C_{UE}
\]

Where $C_{UE}$ is the cost per unit of energy consumed. In India, to encourage consumers for efficient use of electrical energy, many state governments have prescribed different slabs of the tariff. Electricity tariff in New Delhi (India) for domestic consumers varies from ₹3 up to 200 units (kWh) to ₹8 above 1200 units. The use of AC generally falls in a higher consumption slab [9].

2.1.3 Repair cost ($C_R$). Usually, the manufacturers provide warranty for carrying out any repair free of cost in the first year of purchase. It is unpredictable to state when the air conditioner will undergo some breakdown and what price will be applicable to carry out the appliance repair. However, a simple correlation between repair cost ($C_R$), product cost ($C_P$) and unit’s lifetime has been proposed [10] as follows,

\[
C_R = 0.5 \times \frac{C_P}{\text{unit’s lifetime}}
\]

The air conditioner's useful lifetime is assumed ten years (assumption based on compressor warranty by most manufacturers).

2.1.4 Maintenance cost ($C_M$). The air conditioner’s working is affected by prolonged use and surrounding conditions that differ from place to place. Maintenance cost includes the general checks and works carried out for maintaining the AC in good working condition.

After the first year of free maintenance/service, the annual maintenance/service for subsequent years is generally provided by the manufacturer on a yearly payment basis. The maintenance/service cost ($C_M$) has been estimated to 2.5% of the product cost ($C_P$) [10], i.e.

\[
C_M = 0.025 \times C_P
\]

2.2 Payback Period (PP) and Life Cycle Cost (LCC)

Payback period (PP) is the shortest time in which higher initial investment in buying a more efficient AC is received back in terms of its lower running cost i.e., energy cost ($C_E$) [11]. The payback period can be used as a tool by a consumer to select among costly but more energy efficient and economical but less efficient models.

2.2.1 Simple Cost. PP with the simple cost is calculated using the following equation [11]:

\[
PP = \frac{\Delta \text{Initial Cost (IC)}}{\Delta \text{Operating cost (OC)}}
\]

For the first year, annual maintenance cost is zero since the product is under warranty by the manufacturer, and the repair cost has been assumed to incur at the end of the fifth year. Therefore, the
first year's operating cost covers only the energy cost, which is assumed to incur for six months (operating period of AC) in a year.

2.2.2 Compounding Cost. Estimating the future value of money associated with owning and operating the AC unit provides the consumer's criteria to justify its selection. Since the consumer always spends the money either for purchase or operating the AC therefore, the future value (FV) will reflect the compounding effect of money spent during the lifetime of AC. With compounding interest rate, FV of non-recurring present value (PVNR) has been calculated as

\[ FV_{NR} = PV_{NR} \times (1 + i)^n \]  

and FV for the recurring expenditure amounts (AR),

\[ FV_R = \frac{A_{R}(1+i)^n-1}{i} \]  

where 'i' is the rate of interest per annum compounded monthly, and 'n' is the number of months for which future value was calculated.

It may be noted here that costs (\(C_p\) and \(C_R\)) are assumed to incur only once in the unit's lifetime. The energy cost is paid at the end of every month. The maintenance costs are born at the beginning of every year, excluding the year of purchase.

Average operating time per day has been considered as 8 hours, 10 hours & 12 hours. Annual operation of air conditioner has been assumed for 180 days. Interest rate (i) is taken as 3% & 6% per annum and unit's lifetime (n) = 120 months (10 years).

Salvage value at the end of the product's life was not considered as it was assumed to be same irrespective of models.

2.3 Selection of Air Conditioners

Three different inverter air conditioners, i.e., 3-star, 4-star, and 5-star (Daikin make), have been selected with a non-inverter AC as a baseline model for this study. The chosen models have similar capacities, with comparable differences within 5%.

In this study, we assess the compounding cost-based payback periods (PPs) for the higher efficiency models of inverter air conditioners by evaluating additional prices paid for their efficiency enhancement (including costs for their non-efficient features) against the price of baseline efficiency product. Selected models of the split air conditioner and product costs with some critical specifications have been shown in Table 1. In the present analysis, 1.5 ton (5.2 kW) non-inverter AC is chosen as a baseline model with its product cost as ₹31,990.

| Parameter                        | 3-Star Non Inverter AC (Baseline) | 3-Star Inverter AC                  | 4-Star Inverter AC                  | 5-Star Inverter AC                   |
|----------------------------------|-----------------------------------|------------------------------------|------------------------------------|-------------------------------------|
| Retail Price (₹)                 | 31990                             | 37100                              | 39990                              | 42990                               |
| Cooling capacity Rated           |                                   |                                    |                                    |                                     |
| Full/ Half (min.-max.) (kW)      | 5.2                               | 5.0/2.5                            | 5.0/2.5                            | 5.2(2.5-5.7)                        |
| Power consumption Rated          |                                   |                                    |                                    |                                     |
| Full/ Half (min.-max.) (W)       | 1425                              | 1752/615                           | 1680/510                           | 1415 / 475                         |
| ISEER(Wh/Wh)                     | 3.65                              | 3.99                               | 4.17                               | 4.7                                 |
| Operating current (A)            | 6.5                               | 7.71                               | 7.4                                | 6.37                                |
Figure 1 display cash flows for 5-star inverter AC model. The initial cost is paid at the beginning of the investment or purchase of AC. The energy cost \((C_E)\) is paid at the end of months 1 to 6. The pattern repeats for the month 13 to 18 and so on. The final payment of energy cost is made at the end of month 114. The annual maintenance cost \((C_M)\) is paid either at the beginning of the 2nd year or at the end of the first year and after that, \(C_M\) is paid at the annual intervals. The repair cost \((C_R)\) has been taken as one time cost incurred in the middle of the product’s life, i.e., at the end of 5 years. The compound costs are calculated using equations 7 and 8 to estimate the payback periods \((PPs)\) of all three selected models.

\[
\begin{align*}
\text{Figure 1. Cash flow for 5-star inverter AC} \\
\begin{array}{cccccccccccc}
\text{month, n} & 0 & 1 & 12 & 24 & 36 & 48 & 60 & 72 & 84 & 96 & 108 & 120 \\
C_E = ₹ 2655 \text{ paid every 12 months (i.e.12,24,36......108)} \\
C_M = ₹ 1075 \text{ paid every 12 months (i.e.12,24,36......108)} \\
C_E = ₹ 42990 (JC) \text{ (paid at month 0)} \\
C_R = ₹ 2150 \text{ (paid at the end of month 60)}
\end{array}
\end{align*}
\]
3.2 **Effect of operating time**

As shown in figure 3, payback periods for 5-star inverter AC are 3.25 years, 2.33 years, and 2.17 years. Inverter type 4-star and 5-star ACs show higher payback periods than a 3-star inverter AC corresponding to their operating hours. The steeper curves show the AC’s energy consumption phases, and flatter portions are the non-operational slots. The payback periods for all the models decrease with higher usage of the air conditioner, i.e., increase in running time. Thus, more running hours help to recover initial costs to consumers quickly.

![Figure 2. Payback periods of inverter type (5-Star) AC with different unit energy costs.](image)

![Figure 3. Effect of operating hours on payback periods for 5-star AC.](image)

### 3.3 **Effect of interest rate**
According to Table 3, the higher interest rate has a negative influence on the \( PP \)'s of the inverter type ACs. Simple costing presents the lowest \( PP \). For a 3-star inverter AC with 8 hours average daily operating time, \( PP \) increases from 2.33 years with simple cost to 2.42 years (3.9\% increase) at the interest rate of 3\%. \( PP \) moves to 2.5 years (3.3\% increase) if the interest rate is changed from 3\% to 6\%.

**Table 3.** Effect of interest rate on payback periods of inverter ACs

| Usage time | simple cost | \( i=3\% \) | \( i=6\% \) | simple cost | \( i=3\% \) | \( i=6\% \) |
|------------|-------------|---------------|---------------|-------------|---------------|---------------|
| 8 hr       | 2.33        | 2.42          | 2.5           | 3.08        | 3.25          | 3.33          |
| 10 hr      | 2.08        | 2.17          | 2.17          | 2.46        | 2.33          | 2.42          |
| 12 hr      | 1.42        | 1.42          | 1.42          | 2.05        | 2.17          | 2.17          |

The adverse influence of interest rate owes to a relatively higher \( C_P \) difference compared to the monthly variation in \( C_E \) between non-inverter and inverter types. It is also noted that the effect of interest rate on \( PP \) vanishes at longer operating time (12 hours daily).

Figure 4 shows \( PP \)'s at different interest rates with \( ₹4.50 \) unit energy cost. The results establish that simple cost fetches the \( PP \) far earlier than compounding interest rates.

![Figure 4. \( PP \)'s at different interest rates and \( C_{UE} = ₹4.50 \) for 5-star inverter AC](image)

### 3.4 Cost-benefits of efficiency improvement

The difference in the initial cost of a more efficient and a baseline product is supposed to transfer cost-benefits of efficiency improvement to the consumer in energy cost savings. The cost to the energy-saving ratio for 5-star AC is higher than that of 3-star AC (Table 4). These models offer consumers ease of operation (such as mobile app controller) and aesthetic appearance etc. but do not contribute to energy efficiency improvement. Due to higher cost margins for these additional features, the initial cost is significantly higher than that anticipated for just improving efficiency.
Table 4. Energy Savings by more efficient ACs with simple costing and 6% interest rate

| Operation Time | 3-Star Inverter AC | 4-Star Inverter AC | 5-Star Inverter AC |
|----------------|--------------------|--------------------|--------------------|
|                | \( C_{UE} = 8.00 \) | \( C_{UE} = 4.50 \) | \( C_{UE} = 8.00 \) | \( C_{UE} = 4.50 \) | \( C_{UE} = 8.00 \) | \( C_{UE} = 4.50 \) |
| 8 h            | 19740              | 7860               | 25980              | 11520              | 36660              | 20640              |
| 10 h           | 24660              | 9780               | 32460              | 14340              | 45840              | 25740              |
| 12 h           | 29640              | 11820              | 39000              | 17280              | 55020              | 30960              |
| \( i = 6\% \)  |                    |                    |                    |                    |                    |                    |
| 8 h            | 27361              | 10895              | 36011              | 15968              | 50814              | 28609              |
| 10 h           | 34181              | 13556              | 44993              | 19877              | 63538              | 35679              |
| 12 h           | 41084              | 16383              | 54058              | 23951              | 76263              | 42913              |

3.5 Life-cycle cost (LCC) savings

Comparisons of simple cost and compounding cost on LCC savings for 3-star and 5-star inverter ACs with energy tariff \( \₹ 8.00 \) are shown in figure 5.

The LCC savings for a 5-star, 4-star and 3-star inverter ACs running for 12 hours daily (\( C_{UE} = \₹ 8.00 \) and \( i = 6\% \)) are \( \₹ 52,229 \), \( \₹ 36,578 \) and \( \₹ 29,916 \) respectively. Corresponding LCC savings on a simple cost basis are worth \( \₹ 43,195 \), \( \₹ 30,400 \), and \( \₹ 24,147 \).

Figure 5. Life Cycle Cost Savings for 3-Star and 5-Star Inverter ACs (\( C_{UE} = \₹ 8.00 \))

4. Conclusions

The following conclusions are derived from the present study:

1. The energy savings have a remarkable effect on the \( PPs \). Energy cost reductions of about 12\%, 15.8\%, and 22.4\% are achieved with 3-star, 4-star, and 5-star inverter ACs respectively, over the baseline non-inverter AC.
2. The 3-star inverter AC provides the lowest payback period. With unit cost in the highest slab of \( \₹ 8.00 \), \( PPs \) of 3-star inverter AC are 2.5 years, 2.17 years, and 1.42 years for a daily average operating time of 8 hours, 10 hours, and 12 hours respectively. Corresponding \( PPs \) for 5-star inverter AC are 3.25 years, 2.33 years, and 2.08 years.
3. The LCC savings are highest for a 5-star inverter AC. Running for 12 hours daily (\( C_{UE} = \₹ 8.00 \)), the 5-star inverter AC saves \( \₹ 52,229 \) at 6\% compounding interest and \( \₹ 43,195 \) with simple costing.
4. Increasing trends are shown for \( PPs \) with an increase in interest rate.
5. Higher usage time does not increase the percentage energy savings but considerably lowers \( PP \) up
to about 40%.

6. The effect of $C_R$ on $PP$ is not noticeable in the higher tariff slabs. $C_R$ reduces the $PP$ generally at lower unit energy cost.

Finally, it is concluded that selecting the best model based on compounding cost analysis depends mainly on more significant energy savings and higher operating hours. The results show that substantial efficiency improvement can be achieved at a modest increase in the retail price of 3-star inverter AC which will be paid back relatively quickly through energy bill savings. Higher expenditure on more efficient AC models are justified only when electricity prices are high, and AC operates for a longer duration.

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