Techno-economic assessment for revision and ratcheting up of energy performance standards of room air-conditioners up to and including 11 kW (3TR)

Final Draft report

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Report prepared by PwC for CLASP. The Engineering Analysis has been provided by Lawrence Berkeley National Laboratory, (LBNL)

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1. Background

India is the second fastest growing economy in the world[1]. The increasing income levels, affluence and the consequent changing consumer behaviour has helped establish a growing demand for different white goods.

Considering the siginficant rise in energy consumption, it is imperative to adopt energy efficiency measures to reduce the power cosumption. Although the room AC penetration in India is approimately 5%[2] but the expected increase in the power consumption by air conditioning systems need to be reduced through cost effective energy efficiency measures.

The Indian Refrigeration and Air-conditioning Manufacturers' Association (RAMA) reports a positive growth over the next five years. The total energy consumption by air conditioning is expected to rise from 5099 GWh/yr in 2011 to 50,000 GWh/yr in 2031, constituting an almost 10-fold increase[3].

The Bureau of Energy Efficiency, a statutory body under the Ministry of Power, Government of India, launched the Standards and Labeling programme in 2006 on a voluntary basis for both split and window air conditioners upto 11kW cooling capacity. The program was subsequently made mandatory in January, 2010 and since then, it has been very successful in market transformation towards more efficient products. The energy efficiency labeling in India is based on the star rating ranging from one-star to five-star, with five-star being most energy efficient. The energy efficiency of an air conditioner is measured in terms of the EER (Energy Efficiency Ratio) values. These ratings have been revised by the BEE on a periodic basis. The energy efficiency ratings for split ACs were revised for the first time in 2012 and the star rating band was moved up by one level. A 2013 notification by BEE, revised rating bands for both window and split air conditioners for the year 2014-2015 wherein the rating band moved up by one level again. Table 1 shows the current star rating bands for Window & Split ACs which are applicable from January 2014- December 2015.

Table 1: Star rating band from Jan 2014 – Dec 2015

Star rating	EER (W/W)			
	Window AC		Split AC	
	Minimum	Maximum	Minimum	Maximum
1 Star ★	2.50	2.69	2.70	2.89
2 Star ★★	2.70	2.89	2.90	3.09
3 Star ★★★	2.90	3.09	3.10	3.29
4 Star ★★★★	3.10	3.29	3.30	3.49
5 Star ★★★★★	3.30		3.50	

The lower limit of 1 star label defines the Minimum Energy Performance Standard (MEPS) for ACs in India. It implies that, for a room AC to be marketed in the Indian market, it must be at least 1-star or an equivalent EER value. However, MEPS and maximum efficiency labels of the Indian RACs are significantly lower than that compared with other countries as shown in the figure below:

[1] Source: www.indianembassy.org
[2] Source: *Household consumption of various goods and services in India, Ministry of Statistics and Programme Implementation,Govt. of India, 2012.*
[3] Source: *Residential consumptoin of electricity in India, World Bank, 2008*

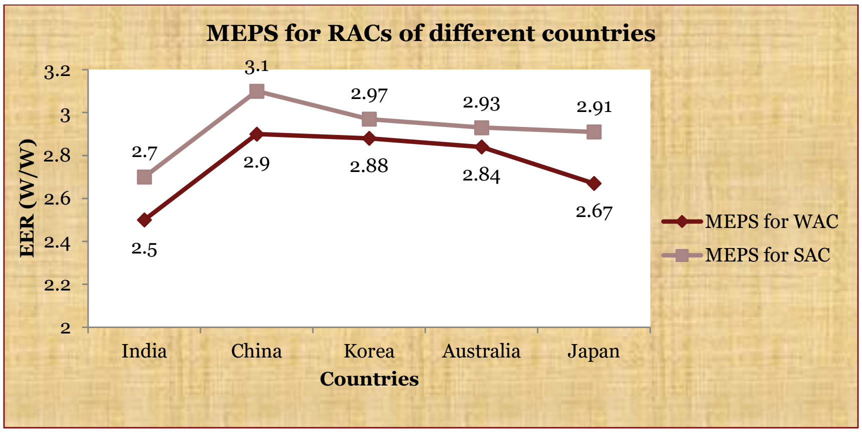


Figure 1 : MEPS for RACs of different Countries

Although comparison of EER values across economies is a good indicator to realize the improvement potential for air conditioners in India, it is equally important to understand the domestic market scenario and priorities to decide most effective policy decisions.

The Bureau of Energy Efficiency envisages transforming the air conditioner market towards more energy efficient products by adhering to the "push-and-pull" strategy. The BEE is providing a policy push at the supply end by promoting design and technology developments, alignment with international trends, handholding of some segments of manufacturers, along with a pull at the demand side by creating demand for energy efficient products by awareness and knowledge dissemination, encapsulated in its Standards and labeling program, policies and regulatory framework. BEE has been revising and ratcheting up the energy standard ratings periodically since inception to provide greater policy-push to move towards energy efficient products.

BEE has initiated action to launch a labeling program for inverter air conditioners, which is the next level efficiency product in the market and will pave the way towards energy efficiency. Parallelly, BEE is actively considering to improve the energy efficiency thresholds of fixed speed air conditioner.

To decide next level of efficiency improvement, there is a need to conduct techno-economic analysis to identify various options to improve energy efficiency. This study has been conducted to assess the current air conditioner market in terms of numbers, types, capacities, supply chain structure, existing technologies and provides insights into the best available options to move to energy efficient products along with their cost effectiveness and saving potential. This study will also attempt to identify various gaps/potential barriers in ratcheting up of energy standards and suggests policy actions and recommendations to improve the energy efficiency standards.

2. Approach & methodology

We have used a Bottom-Up Approach is best suited for carrying out the market & technical assessment of products and capturing the market readiness for moving towards higher efficiency and standards. The major project steps undertaken are presented in Figure 2.

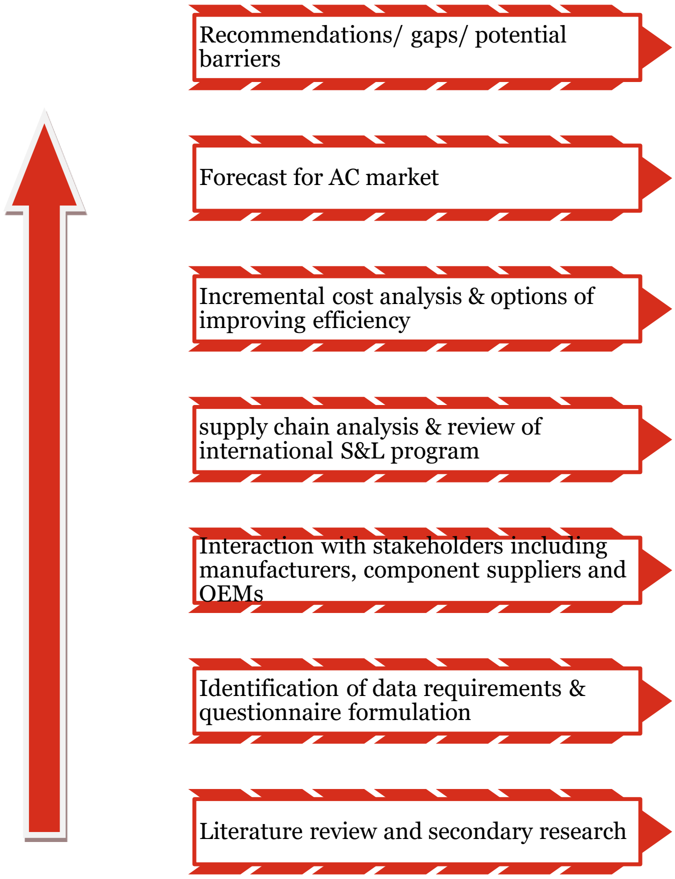


Figure 2 : Bottom up approach

2.1. Data mapping for the project

The team interacted with many stakeholders (clients, manufacturers, associations) and reviewed documents from different sources to gather primary and secondary data for the study. A summary of mapping of the sources to perform different tasks of the study is given below.

S.No.	Task	Clients		Manufacturers Associations				Others			
		BEE	CLASP	AIACRA	RAMA	Manufacturers	Component manufacturers / suppliers	Manufacturers Web	Web (Secondary Research)	India Stat, TV Veopar Journal, CEAMA, etc.	International reports
1	Size of RAC market (category, capacities and number)				√	√			√	√	
2	Market structure, major players and distribution channel				√	√	√		√	√	√
3	Complete supply chain scenario and vendors mapping			√	√	√	√				
4	Status of labeling program	√	√						√		
5	Techno-economic analysis including globally best available technology and cost benefit analysis					√	√	√			√
6	Incremental cost associated with technology up gradation					√	√				√
7	Specifications of different RAC sold in the market							√	√		
8	Forecast for RAC market growth in next 5 years in India[4]					√	√				

[4] Source: *Air Conditioning Systems Market - Global Scenario, Trends, Industry Analysis, Size, Share and Forecast, 2012 – 2018, www.researchmoz.us). India Air Conditioners Market Forecast & Opportunities,2018,*

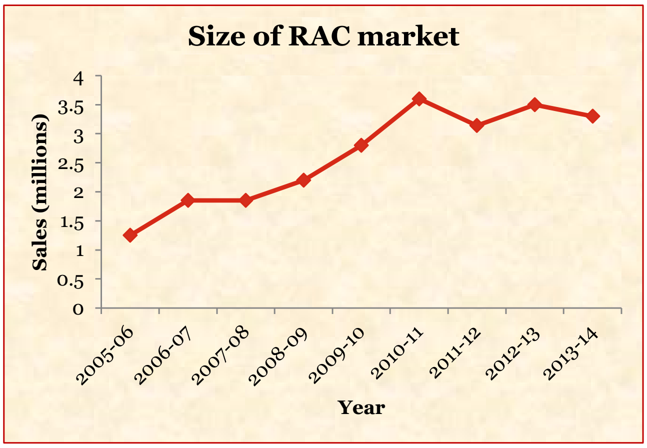
A detailed list of all the stakeholders, whom the team met to gather primary and secondary data for the study is provided:

S.NO	Stakeholder Group	Stakeholder
1		Daikin
2		LG
3		Carrier
4		Hitachi
5		Panasonic
6		Voltas
7		Blue Star
8	Associations	RAMA
9		Highly
10		SIAM
11		Danfoss
12		Tecumseh
13		LG
14		Amber
15		Lloyd
16		DuPont
17		Daikin (AC Manufacturer)
18		Blue Star (AC Manufacturer)
19		LG (AC Manufacturer)
20	Fan Manufacturers	AC manufacturers

3. Market assessment

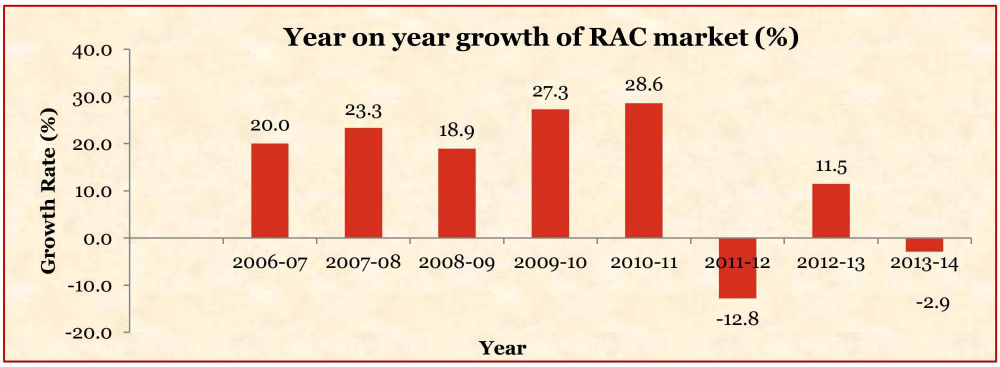
3.1. RAC market size

The Room Air Conditioner (RAC) market comprises of window and split air conditioners. Total size of the RAC market in India stands at 3.3 million units in 2013-14[5] and has been on a high growth trajectory. It grew from a market size of 1.25 million in 2005-06 to 3.3 million units in 2013-14 registering a CAGR of 12.9% as shown in Figure 3. The market has shown positive growth consistently in the last decade, except in the years 2011-12 and 2013-14, where a dip was observed. This observation was confirmed by stakeholders as well, during the interaction.



Year	Size of RACs (millions)
2005-06	1.25
2006-07	1.50
2007-08	1.85
2008-09	2.20
2009-10	2.80
2010-11	3.60
2011-12	3.14
2012-13	3.50
2013-14	3.30
CAGR	12.9%

Figure 3 : RAC market size in MU



[5] Source: *RAMA, Stakeholder Interactions*

Figure 4 : RAC market growth pattern[6]

The growth trend in the RAC market (Base year 2004-05), as evident from Figure 4 has been very consistent in the past decade. The perception of people towards the air conditioner products has undergone a paradigm shift over the past decade from a luxury product to becoming a necessity in hot and humid weather conditions of India. During our consultations with various stakeholders, it was established that the possible reasons for continuous growth of RAC market could be:

- Rising per capita income levels and the consequent improved living standards and comfort requirements.
- Hot and humid weather conditions prevail in most parts of the country for 4-6 months in a year resulting in long cooling seasons.
- Growing construction market in the country is another reason attributing to growing demand for room air conditioners.

As a result, since 2004-05, except the small drop in 2011-12 and 2013-14, RAC sales have grown at an average annual growth rate of around 20%, as shown in Figure 4. Possible reasons for the decline in the market in the two years (2011-12, 2013-14) are as follows:

- The supply chain of RAC market was badly disrupted in 2011 due to floods in Thailand, from where most of the imports of air conditioner components take place.
- Rising inflation and fall in value of Rupee vis-à-vis Dollar could have been one reason leading to high import costs.
- Increase in raw material prices leading to increased product cost.
- Weather- delayed summer (50-60% of RAC sales take place in the second quarter, April-June)
- The ratcheting up of energy standards for RACs in Jan 2014 by Bureau of Energy Efficiency led to technological improvements in air conditioning systems, which in turn led to an increase in the prices.

[6] Source: *RAMA, Stakeholder Interactions*

3.2 Growth forecast for RAC market

This section provides a forecast for RAC market growth for next 5 years in India. In order to develop a forecast, project team identified some major drivers that can have direct or indirect impact on market forecast and demand.

Table 2 : Important drivers for RAC market forecast

S.No.	Important drivers	Conclusions
1	Current household penetration levels of ACs in India?	Around 3.8% households[7]
2	Potential for further growth in household penetration	Considering the fact that: • Hot and humid weather conditions prevail in most parts of country for 4-6 months in a year resulting in long cooling seasons • Rise in per capita income levels and purchasing power Huge potential is available for penetration of ACs in household.
3	Implications of growth on market size	Stakeholder and different manufacturers suggested that RAC market is expected to grow two folds in next five years considering long cooling seasons, high disposable incomes and technological advancements.

The forecast has been made using a simple Compound Annual Growth Rate or CAGR method. CAGR method is used to find the average growth rate on an investment over a period of time, especially in cases where growth rate has fluctuated in one period to the next.

The CAGR calculated from the data given in above table is used to obtain the forecasted values of sales till the year 2020-21. This analysis assumes that the average growth rate achieved in the past (CAGR) will be sustained in the future as well. The forecasted values after application of CAGR value of 12.9% for sales of RACs in India is presented at

Table 3 and the graphical representation is presented at Figure 5.

[7] Source: Euro monitor International

Table 3: CAGR market forecast for RACs

Year	Overall sales (in millions)
2013 -14	3.30
2014 -15	3.73
2015 -16	4.21
2016 -17	4.75
2017 -18	5.36
2018 -19	6.05
2019 - 20	6.83
2020 -21	7.72

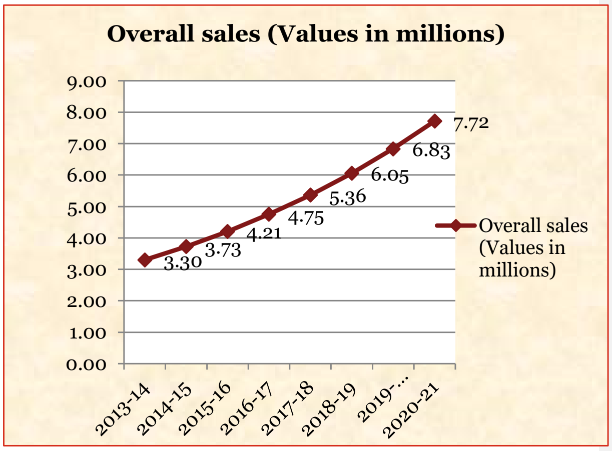


Figure 5: CAGR forecast for RACs till 2020-21

The analysis of data of forecasted sales shows an upward trend with the 2020-21 sales value reaching 7.7 million. This result is consistent with the literature available on the market forecast for Indian RAC industry which predicts a 10-13% CAGR growth in the next 5 years[8]. The market sentiments regarding the growth of the RAC industry in India are very optimistic, with manufacturers expecting the growth witnessed in the past decade to continue in the future as well. This model of forecast is coherent with such market sentiments.

3.3 Market segmentation

RAC market is the biggest market in the HVAC industry in India. Based on the preliminary understanding, RAC market has been characterised under the following broad categories:

1. Types of RAC – split and window

[8] Source: *India Air Conditioners Market Forecast & Opportunities,2018, http://www.techsciresearch.com; Air Conditioning Systems Market - Global Scenario, Trends, Industry Analysis, Size, Share And Forecast, 2012 – 2018, www.researchmoz.us*).

2. Categorization based on capacities

3.3.1 Type of RACs - split and window types (SAC & WAC)

The Indian RAC market, in line with global trends, is gravitating towards a split AC dominated one. In FY 2013-14, the window AC market had gone down to 18% and split ACs accounted for 82% of the overall AC market in India. Some of the factors contributing to this transition are discussed below:

1. **Pricing:** With technology improvement, economies of scale (major factor) and rising market share, the prices of split ACs are decreasing. On the other hand, due to design constraints, higher efficiency, especially beyond 3 stars comes at a higher additional cost for window ACs (as it will anticipate more heat exchange area thus increased cost of sheet metal, heat exchanger tubes and insulation will add to overall system cost for efficiency improvement).
2. **Increasing sensitivity to aesthetics**: Improved living standards have led people to become more sensitive to aesthetics. SACs have obvious aesthetic advantage over WACs as outdoor units (ODUs) of split systems reduce the noise levels in the room. Thus, consumer preference is shifting towards split ACs.

All the factors stated above, along with some other individual specific preferences have led to a gradual transition of the market towards split ACs. The trend in sale of SACs and WACs in India is presented at Figure 6.

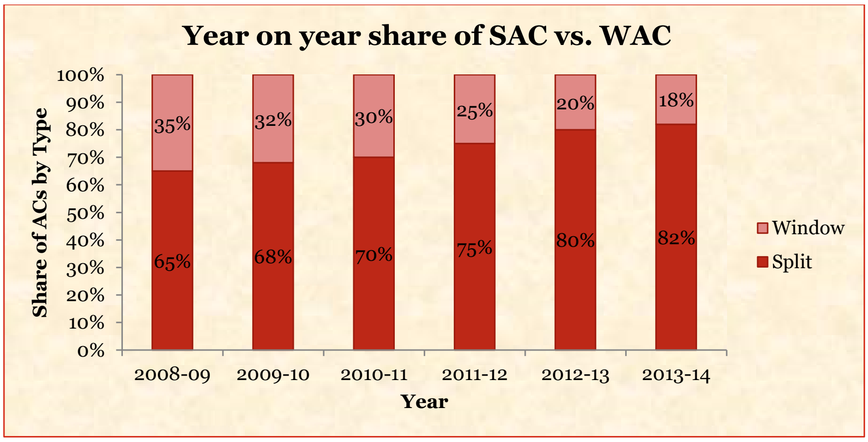


Figure 6 : Year on year share of split vs window AC[9]

Analysis of the data shows that there is a consistent and gradual shift towards the use of split air conditioners in the RAC market. The data shows that the market share of split ACs has increased from 65% in FY 2008-09 to 82% in FY 2013-14. Stakeholder consultations suggest that manufacturers don't see WACs as a priority product, but will keep producing to cater to the needs of different consumers.

3.3.2 Capacities of RACs sold in India

The Indian RAC market mainly comprises the residential sector. Most of the air conditioners sold under this category have capacity ranging from 0.75 to 2.0 tons, with major capacities being 0.75, 1, 1.5 & 2 ton. The analysis of market data and discussions with various manufacturers suggest that 1.5 ton RAC dominates the market in

[9] Source: *Stakeholder interactions*

both split and window AC categories. A comparison has been drawn to assess the share of different capacity RAC in the year 2009-10 and 2013-14.

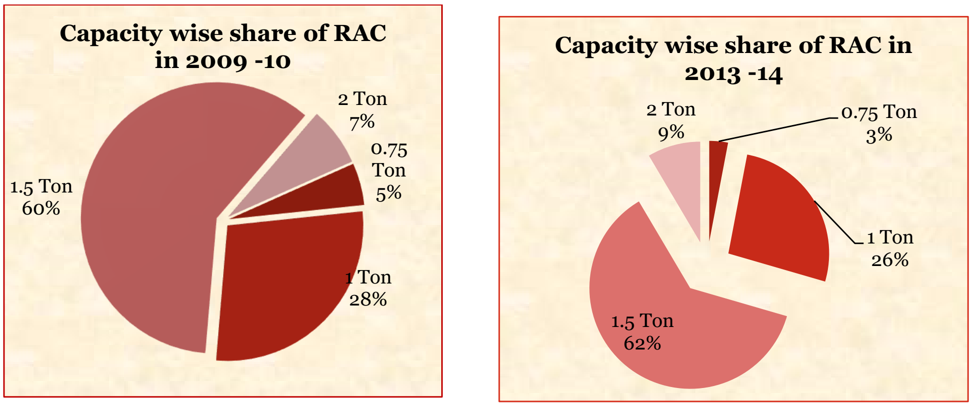


Figure 7 : Comparison of capacity wise share of RAC in 2009 -10 and 2013-14[10]

It can be established from the Figure 7 that, share of 1.5 ton ACs in the total RAC market in the year 2013-14 was around 62%. Share of 1.5 and 2 Ton AC in 2013-14 have seen a growth over 2009-10. These figures may, however, vary for individual manufacturers as well as across different zones.

This increase in percentage of 1.5 Ton and 2 Ton capacity AC can be attributed the very fact that, small commercial establishments have also started using these ACs.

[10] Source: *TV Veopar Journal/Stakeholder Interactions*

3.4 Major manufacturers/suppliers in the Indian RAC market

The Indian RAC market comprises of national manufacturers/ suppliers and multinational companies (MNCs). The RAC industry can be represented in following three categories for better understanding:

- Most of the manufacturers operating in India make/import components and assemble them in their manufacturing facilities. They are classified as Manufacturers/assemblers
- There are some suppliers, who either import the entire system (RAC) or buy the same locally and sell it under their own brand or the suppliers' brand name. These entities are classified as traders in the RAC market.
- There are some manufacturers which are both manufacturers and traders.

Figure 8 below shows a simple illustration of the same:

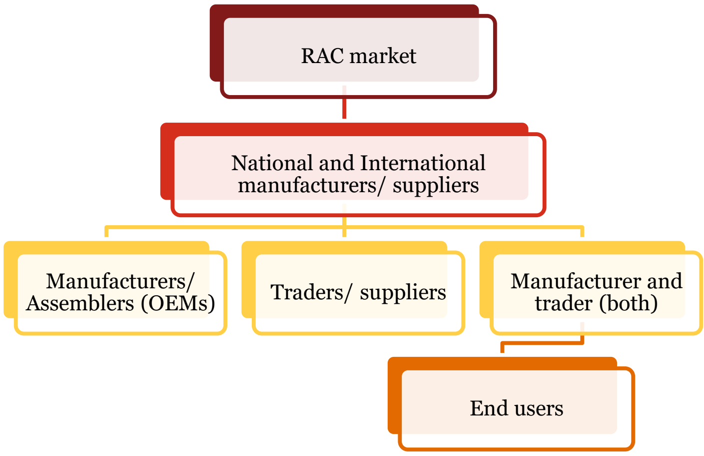


Figure 8 : A simple illustration of the entities in the RAC market

RAC market in India is mainly covered by close to 10 key manufacturers. With our understanding, we divide the manufacturers in four categories which are national as well as international manufacturers (Japanese, Korean and others). While the Japanese and Korean players hold a major share in the market, Indian players like Voltas, Blue Star and Videocon also play a major role in driving the highly competitive market. List of major manufacturers/ suppliers operating in India are provided in Table 4.

Table 4 : Key MNC & national RAC manufacturers/ suppliers

Multi-National Companies (MNC)			National
Japanese	**Korean**	**Others**	**Indian**
Daikin	LG	Carrier	Blue Star
Hitachi	Samsung	Whirlpool	Voltas
Panasonic		Haier	Godrej
		Gree	Videocon
		Midea	Lloyd

The categorization given in the Table 4 mentions the manufacturers/suppliers with major market share and is not an exhaustive list of the manufacturers/ suppliers operating, manufacturing and/or supplying RACs in the Indian RAC market. The data for annual sales of RACs for different manufacturers and their respective market share in the year 2013-14[11] are presented in Table 5 and

Figure 9.

Table 5 : Manufacturer wise units sold in 2013-14

S.No.	Brands	Units
1	Voltas	700000
2	LG	600000
3	Panasonic	500000
4	Daikin	400000
5	Samsung	300000
6	Hitachi	200000
7	Carrier	150000
8	Blue Star	150000
9	Others	300000
Total		3300000

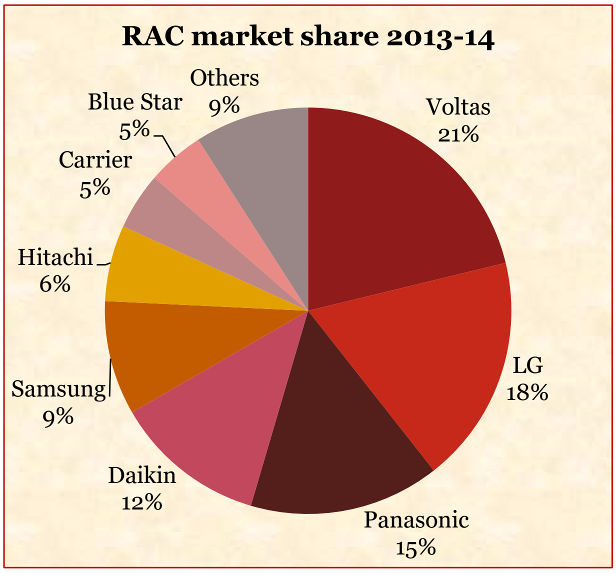
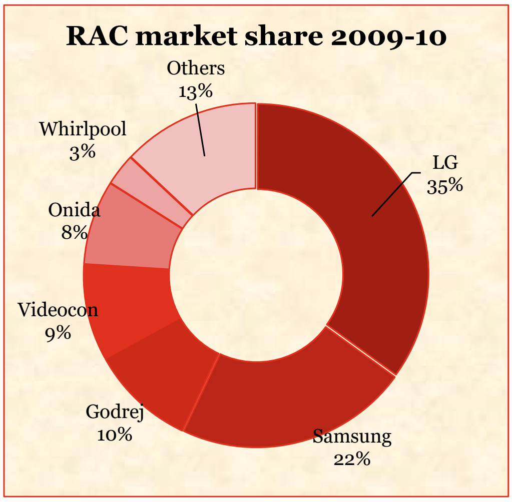


Figure 9 : Market share of different RAC manufacturers in 2013-14

The analysis of data for the year 2013-14 shows that Voltas is the market leader in RAC segment with around 21% market share. Voltas along with LG, Panasonic and Daikin together constituted more than 65% of the total RAC market in India in the year 2013-14.

RAC market in India is a highly competitive market with plethora of Indian and foreign players battling for top share in the market. Through innovation and pricing strategies, manufacturers are trying to tap more and more customers in this RAC market. Due to the huge competition, the market share portfolio of RAC sector is very volatile. In last few years, Voltas has been able to increase its market share. One of the reasons here could be penetration of RAC market more in middle class segment of consumers, who are price conscious. For example, the comparison between the market share portfolios of RAC segment during two financial years, i.e. 2009-10 and 2013-14 is presented at Figure 10.

[11] Source : *Stakeholder interactions/ CEAMA*



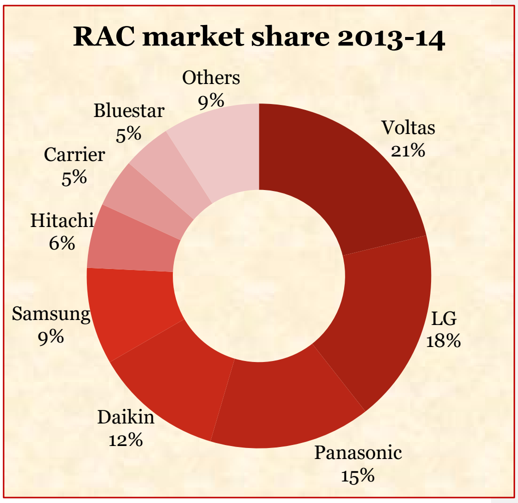


Figure 10 : Comparison of RAC market share in 2009 -10 and 2013-14[12]

The market data suggests that LG was the market leader in RAC segment in 2009-2010 with around 35% share of the overall RAC market. The analysis also suggests that LG, Samsung, Godrej and Videocon together had more than 75% of the RAC market in India.

Over a period of four years, Voltas has captured the market of RACs in India. LG, Samsung and Godrej have lost their hold on the market and their market share has dropped by more than 10% each (As high as 17%, in case of LG). This share of sales of RAC has been tapped by companies like Voltas, Panasonic and Daikin which have witnessed a growth in their market share by more than 10%. One of the reasons for Voltas being emerged as the market leader is providing low to medium price products in the market. It also points toward price sensitivity of the Indian market.

[12] Source: *Stakeholder interactions*

4 Status of labeling program

Standard & labeling programs around the globe have been used as a tool to transform the market towards efficient products & technologies. These programs define minimum efficiency levels, which act as base to design new interventions to move to higher efficiency levels. The importance of such programs is well understood globally and different countries have developed standards & labels for different products.

India followed global trends and launched its labeling program for room air conditioner, in the year 2006 which was further moved to mandatory phase in 2010. It becomes imperative to study national as well as international programs to assess the feasibility to adopt best international practices for achieving next level of efficiencies. The approach is to divide this analysis into two parts, viz. analysis of Indian program, and a brief overview of global programs.

4.1 Analysis of standard & labeling program for RACs in India

BEE initiated the standard & labeling program for RAC's in the year 2006 with a voluntary label, which became mandatory in the year 2010. These labels were framed as per the requirements mentioned in *Indian Standards IS 1391 Part1 & Part2*. BEE has been periodically updating the energy standards by ratcheting up the scheme by one, which implies that the 2 star becomes 1 star, 3 star becomes 2 star, etc. **Table 6 - Table 8 & Table 9** shows transition of energy standards for air conditioners since it became mandatory in 2010.

Table 6 : Star rating band for window & split ACs from 1 May 2011 to 31 December 2011

Star Rating	EER (W/W)	
	Minimum	Maximum
1 Star★	2.30	2.49
2 Star★★	2.50	2.69
3 Star★★★	2.70	2.89
4 Star★★★★	2.90	3.09
5 Star★★★★★	3.10	

Standards for Split AC were upgraded next higher level of EER in 2012 while those for Windows ACs were kept the same. Another notification in 2013, revised the standards for both the split and windows ACs and the standards were ratcheted up to the next higher level of EER.

Table 7 : Star rating band for window & split ACs from 1 Jan 2012 to 31 December 2013

Star Rating	EER (W/W)	
	Minimum	Maximum
1 Star★	2.50	2.69
2 Star★★	2.70	2.89
3 Star★★★	2.90	3.09
4 Star★★★★	3.10	3.29
5 Star★★★★★	3.30	

* The above table has been brought into effect from 9 January 2012 by the Bureau of Energy Efficiency.

Table 8 : Star rating band for split ACs from 1 Jan 2014 to 31 December 2015

Star Rating	EER (W/W)	
	Minimum	Maximum
1 Star★	2.70	2.89
2 Star★★	2.90	3.09
3 Star★★★	3.10	3.29
4 Star★★★★	3.30	3.49
5 Star★★★★★	3.50	

Table 9 : Star rating band for window ACs from 1 Jan 2014 to 31 December 2015

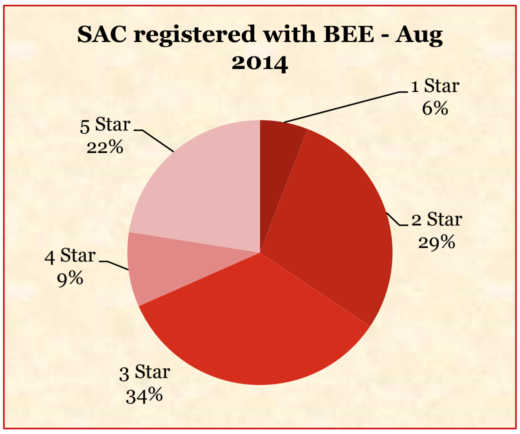
Star Rating	EER (W/W)	
	Minimum	Maximum
1 Star★	2.50	2.69
2 Star★★	2.70	2.89
3 Star★★★	2.90	3.09
4 Star★★★★	3.10	3.29
5 Star★★★★★	3.30	

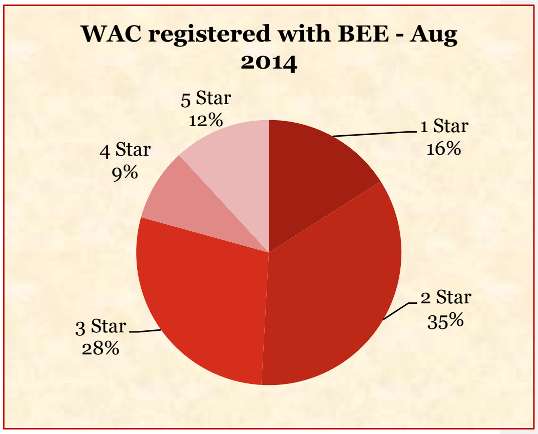
4.1.1 Manufacturers involvement in BEE's standard & labeling program

In order to assess the number of star rated RAC in the country, project team also reviewed the number of models registered by manufacturers with BEE in different capacity and star ratings. This analysis was helpful to assess the manufacturer's priority with regard to capacities and star ratings.

Table 10 : Number of SAC and WAC registered models with BEE (In 2014)

S.No.	Star rating	Number of split AC registered models	Number of window AC registered models
1	1 Star ★	55	27
2	2 Star ★★	269	59
3	3 Star ★★★	320	48
4	4 Star ★★★★	86	15
5	5 Star ★★★★★	212	20
Total		**942**	**169**





It can be established from Figure 11 that most of the models are registered in 2 and 3 star category followed by 5 star in SAC. In case of WAC most of the models are registered in 2 and 3 star category. *It appears that 2 and 3 star is most preferred among SAC and WAC category.*
Different manufacturers have registered different number of models with BEE among 1, 2, 3 4 and 5 star ratings. The number of models registered by each manufacturer is provided at the Table 11.

Table 11 : Manufacturer wise SAC and WAC registered with BEE – Aug 2014[13]

S.No.	Manufacturer	Number of split AC model registered	SAC registered in different star ratings	Number of window AC model registered	WAC registered in different star ratings
1	LG	124	2, 3, 4 & 5	33	1, 2, 3, 4 & 5
2	Hitachi	91	1, 2, 3, 4 & 5	24	1, 2, 3, 4 & 5
3	Voltas	81	2, 3, 4 & 5	24	1, 2, 3 & 5
4	Carrier	80	1, 2, 3, 4 & 5	13	1, 2 & 3
5	Blue Star	47	2, 3 & 5	7	2 & 3
6	Panasonic	44	2, 3, 4 & 5	6	2, 3 & 5

Figure 11 : Star rating wise SAC & WAC registered with BEE till Aug 2014

9	Daikin	30	1, 2, 3, 4 & 5	NA	NA
10	Others	372	1, 2, 3, 4 & 5	61	1, 2, 3, 4 & 5
Total		**942**		**169**	

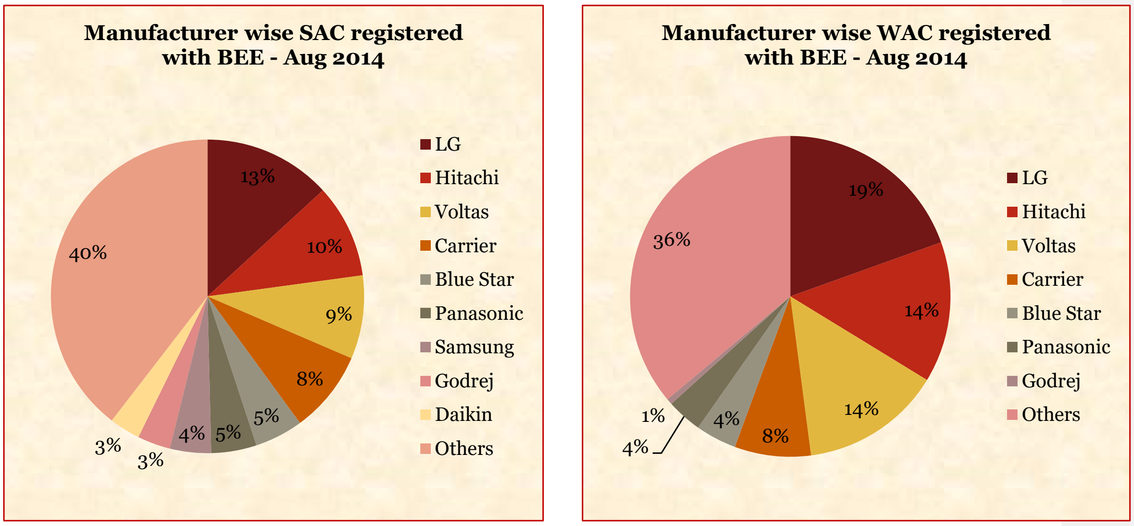


Figure 12 : Manufacturer wise SAC & WAC registered with BEE till - Aug 2014

It can be established from Table 11 and Figure 12 that:

- *LG, Hitachi, Voltas, carrier, Blue Star & Panasonic together have registered more than 50 % of SAC and WAC models with BEE. LG and Hitachi have registered maximum number of models with BEE.*
- *Daikin and Samsung are not selling window AC's in India and have no model registered with BEE.*

[13] Source: *BEE website*

- *Earlier only LG & Hitachi had models with 5 star in WAC, but nowadays Voltas, Panasonic and other players have also registered their 5 star models with BEE.*

4.2 Global standard & labeling programs

RACs were among the first few products considered & realized globally as the major energy consuming appliance to be covered under Standard & Labeling programs. Project team also looked at analysis of various programs around the globe for RACs. Key features of programs for different countries and India are presented at Table 12.

Table 12 : Overview of Indian & International RAC programs[14]

Countries	Implementing Organization	Policy Name	Label Type	Test Standards/ Procedure	Scope
India	Bureau of Energy Efficiency	AC Notification/Gazette (Schedule 3 - Room Air Conditioners)	Mandatory – since 2010 (2012 Split AC revision, 2014* Split, windows AC revision)	IS 1391 (Part I) IS 1391 (Part II)	Single phase split & unitary ACs of rated cooling capacity of **11 kW/9000 Kcal/hour**
Australia	Department of Climate Change & Energy Efficiency (DCCEE)	Performance of electrical appliances - Air conditioners and heat pumps - Energy labelling and minimum energy performance standards (MEPS) requirements	Mandatory since 1987 – (2011*)	AS/NZS 3823.1.1-1.4	Single phase non- ducted air conditioners of vapor compression type for household application & MEPS requirement for single-phase & three phase AC of vapor compression type with cooling capacity up to **65 kW.**
China	National Development & Reform Commission (NDRC) and General Administration of Quality Supervision, Inspection & Quarantine of China(AQSIQ)	China Energy Label - Room Air Conditioners	Mandatory-since 2005 (2010*)		Completely closed type electric motor compressor type AC, with cooling capacity below **14kW**
European Union	European Commission - DG Energy	COMMISSION DELEGATED REGULATION (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with	Mandatory-since 2002 (2011*)	EN 14511, EN255-1 , EN 814-1	Electric mains - operated ACs with a rated capacity of **12 kW** cooling or heating.

[14] Source: *http://www.clasponline.org/ResourcesTools/Tools/EconomyFinder*

		regard to energy labelling of air conditioners			
Japan	Energy Conservation Centre, Japan	Top Runner Program for Air Conditioners	Mandatory-since 2006 (2008*)	JIS C 9612:2005; JIS B 8616:2006	Cooling - cum-heating ACs & dedicated cooling ACs with cooling capacity up to **50.4 kW**
Korea	Korea Energy Management Corporation (KEMCO)	MEPS for Air Conditioners	Mandatory-since 1992 (2009*)	KS C 9306-2002	1. AC of rated cooling power consumption of not more than **7.5kW** & rated cooling capacity not more than **23kW**. 2. If heater is present, rated power consumption of heater shall not be more than **5kW**
USA	Federal Trade Commission	16 CFR Part 305	Mandatory-since 2007 (Energy Guide)	10 CFR Part 430 Appendix F to Subpart B	A consumer product, other than a packaged terminal AC, which is powered by a single phase electric current & which is an encased assembly designed as a unit for mounting in a window or through the wall for the purpose of providing delivery of conditioned air to an enclosed space. Rated cooling/heating capacity up to **19kW**

*Denotes most recent effective revision

4.2.1 *MEPS levels for split & window ACs- A global overview*

Comparison of room air conditioner regulations across countries is not a straightforward task, because ratings are generally defined by cooling capacity ranges, which vary from one country to another based on the building design & area. Furthermore, most countries define different standards for various technologies of window and split units. The Indian levels define it for the two broad classes i.e. window & split AC, the energy standard requirements for different countries have been extracted from secondary sources and presented at Table 13.

Table 13 : Energy Efficiency Ratio (W/W) under S&L program for various countries[15][16][17]

	Rating Plan		**0**	**1**	**2**	**3**	**4**	**5**
Country	**Product Category**							
		2012		2.30	2.50	2.70	2.90	3.10
		2014		2.50	2.70	2.90	3.10	3.30
		2012		2.50	2.70	2.90	3.10	3.30
		2014		2.70	2.90	3.10	3.30	3.50
	Rating Plan (Label Class)			**Class 3**	**Class 2**	**Class 1**		
	Window Type		-	2.90	3.10	3.30	-	-
		CC <= 4500 W	-	3.20	3.40	3.60	-	-
		4500 W <= CC <= 7100 W	-	3.10	3.30	3.50	-	-
		7100 W <= CC <= 14000 W	-	3.00	3.20	3.40	-	-
	Casement, window, single split (Non-inverter)		<2.50	>=2.50	>=2.78	>=3.20	NA	-
	Multi Split (non-inverter)		<2.64	>=2.64	>=2.92	>=3.34	NA	-

	Rating Plan	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
	EER	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25

	Rating Plan			**A**	**B**	**C**	**D**	**E**	**F**	**G**
	EER			>3.20	3.00-3.20	2.80-3.00	2.60-2.80	2.40-2.60	2.20-2.40	<=2.20
	Rating Plan	**A+++**	**A++**	**A+**	**A**	**B**	**C**	**D**	**E**	**F**	**G**

[15] Source : *Energy Star- Room Air Conditioner Key Product Criteria*

[16] Source: *Market Study for Harmonization of Energy Efficiency Standards for Air Conditioners & Refrigerators in South East Asia – by International Copper Association (15th November 2010)*

[17] Source: *Cooling Benchmarking Study – Mapping Component Report by CLASP (June 2011)*

	SEER[18]	≥ 8.50	8.50 > SEER ≥ 6.10	6.10 > SEER ≥ 5.60	5.60 > SEER ≥ 5.10	5.10 > SEER ≥ 4.60	4.60 > SEER ≥ 4.10	4.10 > SEER ≥ 3.60	3.60 > SEER ≥ 3.10	3.10 > SEER ≥ 2.60	2.60 > SEER
	SCOP[19]	≥ 5.10	5.10 > SCOP ≥ 4.60	4.60 > SCOP ≥ 4.00	4.00 > SCOP ≥ 3.40	3.40 > SCOP ≥ 3.10	3.10 > SCOP ≥ 2.80	2.80 > SCOP ≥ 2.50	2.50 > SCOP ≥ 2.20	2.20 > SCOP ≥ 1.90	1.90 > SCOP

	Federal Standard EER		**With louvered sides**[20]	**Without louvered sides**
	Cooling Capacity < 1758 W			
	1758<=Cooling Capacity<2344			
	2344<=Cooling Capacity<4103		>=2.87	
	4103<=Cooling Capacity<5861		>=2.84	
	Cooling Capacity >= 5861		>=2.49	
	Cooling & Heating			
	Casement- Only[21]		>=2.55	
	Casement- Slider[22]		>=2.78	
		Cooling Capacity<2344 W		>=2.49
		Cooling Capacity>=4103 W		>=2.34
		Cooling Capacity<5861 W	>=2.64	
		Cooling Capacity>=5861 W	>=2.49	

Most of the countries have referred the methodology for capacity and efficiency ratings from ISO 5151: 2010 and have incorporated the same in their national standards. MEPS levels for room air conditioners in India are relatively low as compared to other countries. *In other countries MEPS levels vary for different cooling capacities within the maximum predefined cooling capacity limit for the whole program but in case of India it is same throughout for cooling capacity up to 11 kW.*

It is imperative to understand that the EER values can't be directly compared across different countries because of differences in the test procedures and test conditions followed in each country. However, a comparison between the MEPS values across various countries provides insights into scope of improving the policy framework and the standards in our country.

[18] Source: *Cooling Benchmarking Study – Part 2 – Benchmarking Component Report by CLASP (June 2011)*
[19] Source: *Cooling Benchmarking Study – Part 2 – Benchmarking Component Report by CLASP (June 2011)*
[20] Source: *Exterior side vents on a RAC that permit air exchange by enhancing airflow over the outdoor coil.*
[21] Source: *A RAC designed for mounting in a casement window in an encased assembly with a width of 14.8 inches or less and a height of 11.2 inches or less*
[22] Source: *A RAC with an encased assembly designed for mounting in a sliding or casement window with a width of 15.5 inches or less.*

5 Specifications of RAC products sold in the market

5.1 Indian market

In order to understand the readiness of the RAC market to adopt revisions and ratcheting up of energy performance standards, it is worthwhile to first analyze the present level of efficiency of products sold in the Indian market. The scope of this analysis is limited to fixed speed compressor room air conditioners, both split and window ACs. To have an understanding of various split and window AC units being sold in the Indian market, project team collated information pertaining to the technical specifications of existing models along with their pricing in the market. This information was captured through meetings with relevant stakeholders and manufacturers and review of manufacturer's websites/product brochures. The specifications of both split and window ACs currently being sold in the market are discussed in this chapter. The brands considered for the analysis are listed in the Figure 13. These brands, according to the 2013-14 data, comprise of 90% of the total RAC market in India.

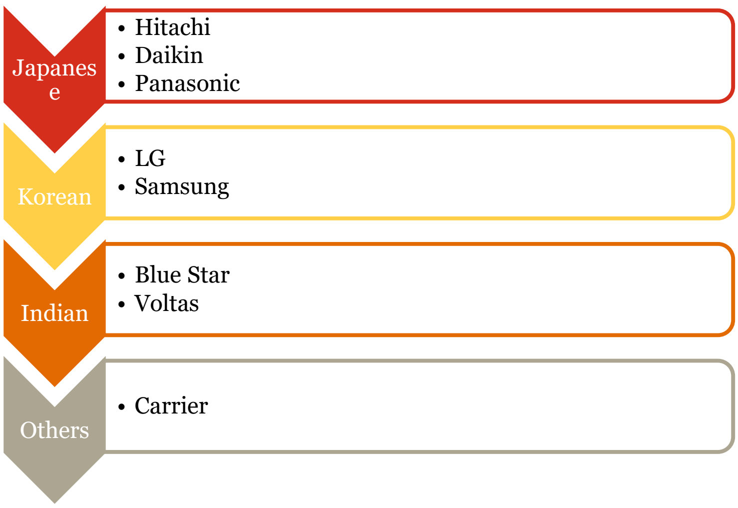


Figure 13 : Brands for capturing specifications of RACs

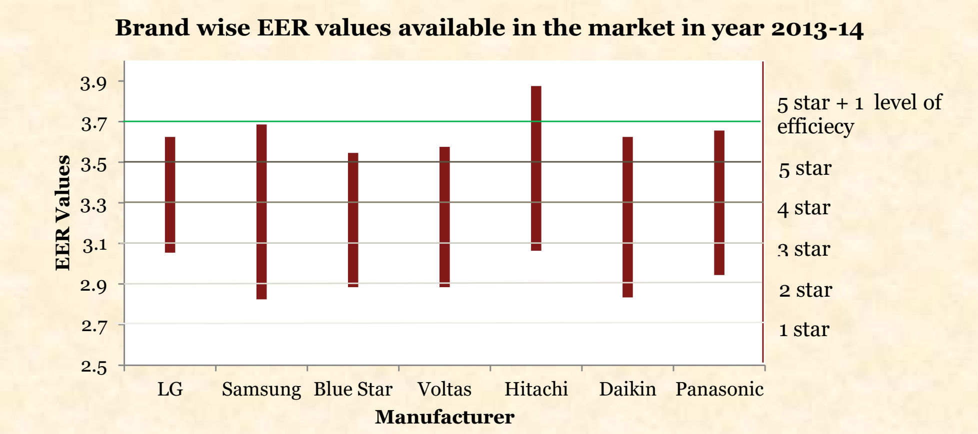
5.1.1 Split Air Conditioners

A preliminary analysis of the specifications of these brands suggests that the Indian market is mainly driven by 1.5 ton split air conditioner units as maximum models have been introduced in this category by different manufacturers. The summary sheet of the specification and price range of the split air conditioner units of these selected brands is provided at Table 14 and the EER range for different brands is presented at Figure 14.

Table 14 : Specification of split Air Conditioners (fixed speed compressors) [23][24]

Brand	Tonnage Range	MOP / Base model (Rs.)	Star Rating	Cooling Capacity Range (Watts)	Power Input (Watts)	EER Watts/Power Input (Watts)	Compressor Type	Refrigerant
Japanese Manufacturers								
Hitachi	1.0-2.0	33300-42300	2,3,5	3380-7020	960-2160	3.09-3.85	Rotary	*
Daikin	0.75-2.0	33800 – 43600	1,2,3,4,5	2600-6600	765-2237	2.86-3.60	Rotary	R32,R22
Panasonic	0.75-2.0	28990-40000	2,3,4,5	2640-6700	990-2170	2.97-3.63	*	*
Korean Manufacturers								
LG	1.0-2.0	30990-41000	2,3,4,5	3420-6350	1110-2000	3.08-3.60	Rotary	R22
Samsung	1.0-2.0	27600-36300	2,3,5	3500-6300	1230-1950	2.85-3.66	*	R22
Indian Manufacturers								
Blue Star	1.0-2.0	*	2,3,5	3265-6365	1080-2100	2.91-3.52	Rotary	R22, R410a
Voltas	0.75-2.0	27290-38500	2,3,5	2600-6300	893-2164	2.91-3.55	High EER Rotary	R22
Others								
Carrier	1.0-2.0	32600-43000	1,2,3,4,5	3470-6795	950-2378	*	*	R22,R410a

* Couldn't be captured



[23] Source: *Manufacturers Websites*

[24] *The table has been created from data available on manufacturer websites. Thus, there might be some variation between the models registered with the BEE and those mentioned in the table above. One reason being that some models registered with the BEE earlier might have been discontinued after the up gradation of the star label bands in 2014.*

Figure 14 : EER levels of different brands of split AC in the year 2013 -14

The key takeaways from the above analysis are:

- Presently, most of the AC manufacturers are using R22 as the refrigerant. Considering the fact that R22 has to be phased out, almost all the AC manufacturers have started using R410a. Daikin started using R32 for most their models.
- In case of split AC's, manufacturers have achieved EER value as high as 3.85, which potentially considered to be plus one efficiency level from current 5 star level. Apart from that, 3.63 and 3.66 EER models are already available in the market.

5.1.2 Window Air Conditioners

Initial analysis of the specifications shows that most of the windows ACs are being manufactured with a 1.5 ton capacity. Over the years, the market share of windows ACs in the RAC segment has declined sharply, with further decline anticipated in future. Gradually, windows ACs are phasing out from the market with brands closing down their windows ACs product lines. Major reasons for this shift include higher efficiency levels of split ACs vis-à-vis window ACs and the narrowing gap in the prices between the two products. The summary sheet of the specification range of the windows air conditioner units of these selected brands is provided at and the EER range for different brands is presented at Figure 15.

Table 15 : Specification of window air conditioners[25][26]

Brand	Tonnage Range	MOP / Base model (Rs.)	Star Rating	Cooling Capacity (Watts)	Power Input (Watts)	EER Watts/Power Input (Watts)	Compressor Type	Refrigerant
Japanese Manufacturers								
Hitachi	1.0-2.0	27000-31900	1,2,3,5	3500-6160	1030-2425	2.54-3.50	Rotary	*
Daikin	*Product Not Available on Public Domain*							
Panasonic	*Product information not available on Public domain*							
Korean Manufacturers								
LG	0.75-2.0	22990-29000	1,2,3,4,5	2400-5860	940-2250	2.55-3.34	Rotary	R22
Samsung	*Product Not Available on Public Domain*							
Indian Manufacturers								
Blue Star	0.75-2.0	*	2,3	2515-5850	925-2080	2.71-2.93	Rotary	R22
Voltas	0.75-2.0	19990-29000	1,2,3,5	2500-6000	922-2265	2.65-3.31	High EER Rotary	R22
Others								
Carrier	1.0-2.0	27050-33450	1,2,3	3675-6330	1197-2280	*	*	*

* Couldn't be captured

[25] Source: *Manufacturers Websites*
[26] *The table has been created from data available on manufacturer websites. Thus, there might be some variation between the models registered with the BEE and those mentioned in the table above. One reason being that some models registered with the BEE earlier might have been discontinued after the up gradation of the star label bands in Jan 2014.*

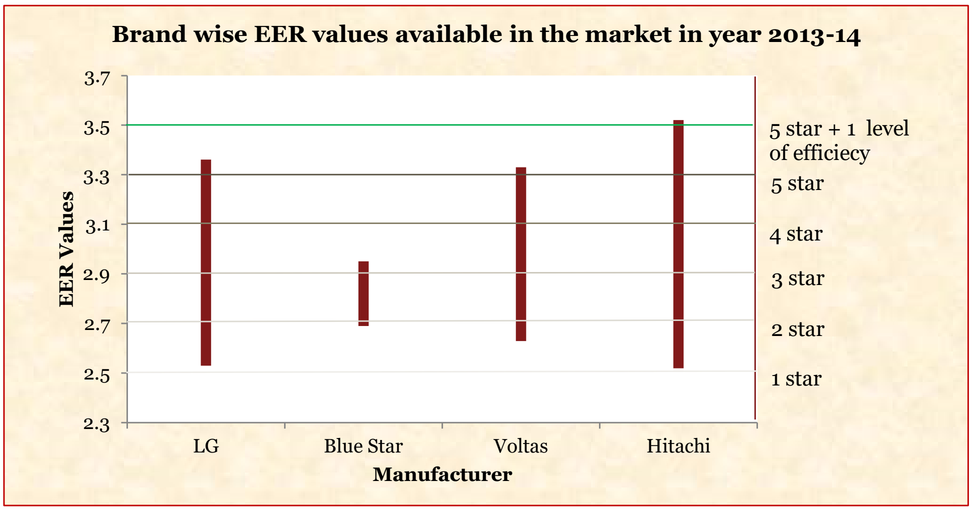


Figure 15 : EER levels of different brands of window AC in the year 2013 -14

The key takeaways from the above analysis are:

- Manufacturers like Samsung and Daikin have stopped manufacturing window AC's. Product information is not available on the public domain for Samsung, Daikin and Panasonic.

  Only a few brands have 5 star window ACs available in the market. One manufacturer has achieved plus one level of efficiency compared to current 5 star level for windows.

5.2 International markets

This analysis presents the specifications of room air conditioners (RACs), both split and window air conditioners, being sold in international markets. The markets considered for this analysis are:

- Australia – New Zealand (***Source***: *http://reg.energyrating.gov.au)*
- Singapore (***Source***: *https://app.mels.nea.gov.sg*)
- United States of America

The specifications of RAC models recorded for these manufacturers include:

- Brand and Model name
- Cooling Capacity
- Power Input
- EER/COP

Calculation for EER has been performed by dividing the rated cooling capacity by rated power input for the RACs.

5.2.1 Split Air Conditioners

The detailed specifications of the SAC models recorded and the analysis is presented below:

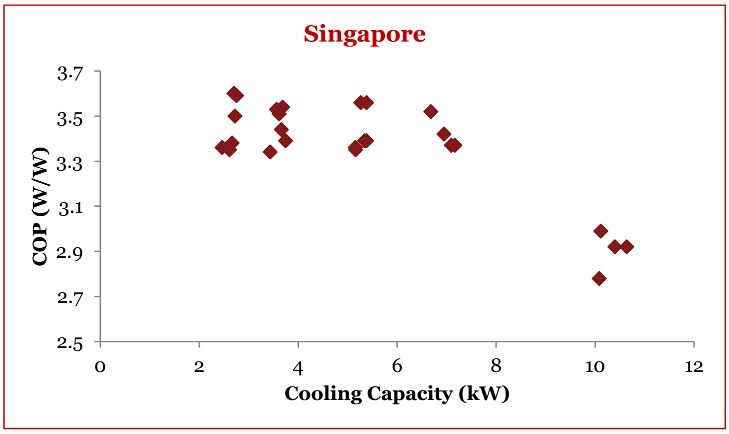


Figure 16: EER levels versus cooling capacity for SACs - Global

The analysis highlights following key points about split AC market in Singapore:

- Most of the SAC products being sold in Singapore market lie in 2000 -7000 W cooling capacity range.
- COP levels observed in the products recorded lie in the 3.3 -3.6 range. As observed earlier, SACs sold in Indian markets also vary from 3.1 – 3.6, which indicates that efficiency levels in Indian markets are at par with Singapore markets for fixed air conditioners.

5.2.2 Window Air Conditioners

The detailed specifications of the WAC models recorded and the analysis is now presented.

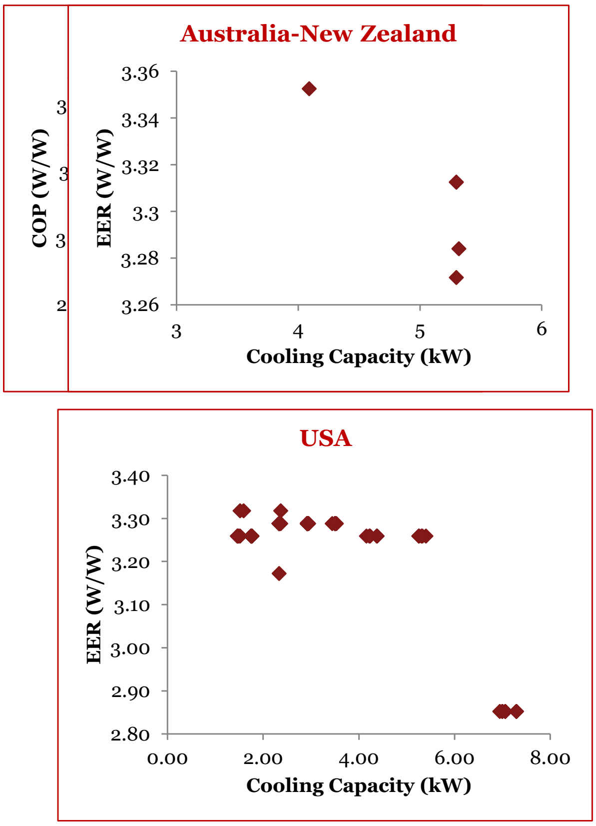


Figure 17: EER levels versus cooling capacity for WACs - Global

The analysis highlights following key points about WAC market in Singapore, Australia-New Zealand and US:

- Most of the WAC products recorded in Singapore market lie in 2000 -5000 W cooling capacity range.
- Models recorded in Australia-New Zealand market lie in higher cooling capacity range (4000 -5500 W).
- Most of the models recorded in USA lie in 1500-5000 W cooling capacity range.
- COP levels observed in the products recorded in Singapore market lie in the 2.9 -3.3 range. Efficiency levels recorded in Australia-New Zealand market vary from 3.27-3.35 while that for US varies from 2.85-3.32. WACs sold in Indian markets also vary from 2.5 – 3.3, which indicates that efficiency levels in Indian markets are at par with Singapore, Australia-New Zealand and US markets.

6 Supply chain scenario

6.1 Air conditioner operating mechanism

Air conditioners work on the basic principle of the *Refrigeration Cycle*. Heat is absorbed when evaporation of the refrigerant fluid occurs and heat is released when condensation of the refrigerant occurs. Refrigerant is the working fluid which evaporates and condenses in the evaporator and condenser while circulating inside the refrigeration loop. Figure 18 shows different components of Room Air Conditioner (RAC).

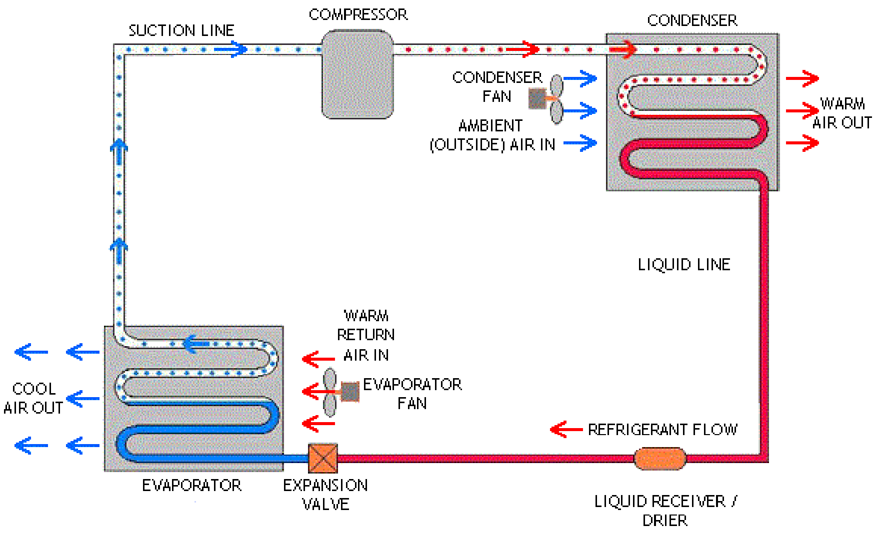


Figure 18 : Air conditioner cyclic diagram[27]

Refrigerant flows in the form of a low pressure liquid through the evaporator pipes where it absorbs heat from the air flowing from inside the room into the air conditioner due to the low pressure created by the fan installed in the indoor unit next to the heat exchanger. The liquid refrigerant absorbs the heat and gets converted to vapor. This refrigerant passes through the compressor where it is compressed to a high pressure vapor. The vapor flows through the condenser pipes where air, sucked into the air conditioner from outside, absorbs heat from the refrigerant vapor and the vapor after releasing heat to the air turns into liquid again. This high pressure liquid moves to the expansion valve. The valve restricts the flow of the fluid and reduces its pressure as it leaves the expansion valve. The low pressure liquid flows through the evaporator and absorbs heat from the inside air and the cycle is repeated.

The components of a room air conditioner can be broadly divided into 3 main categories as mentioned below:

- **Main Parts**- The components responsible for the cooling effect.
- **Auxiliary Parts** – Components ensuring clean & healthy operation.

[27] Source: *http://www.prodomestics.com/air-conditioning.shtml*

- **Control Parts** – Components ensuring optimum & efficient operation of main parts.

Key components falling under above categories are provided in Figure 19.

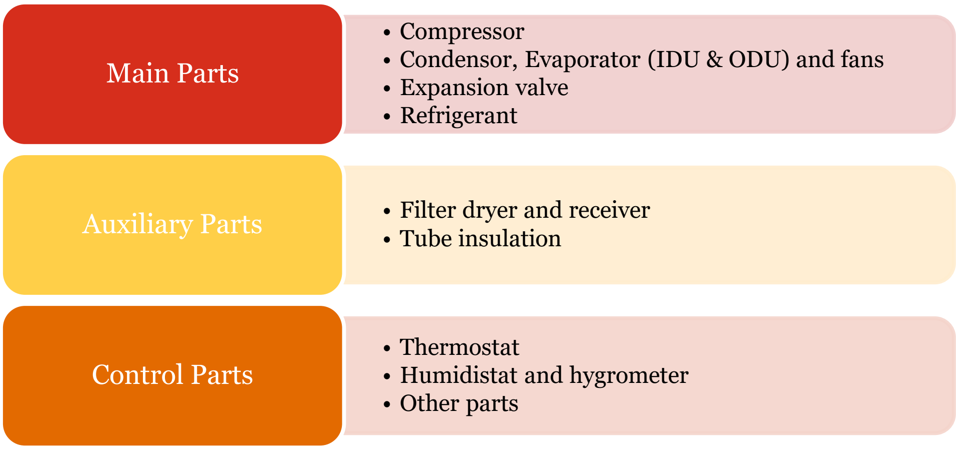


Figure 19 : Key components of AC

6.2 *Supply chain structure*

6.2.1 *RAC supply chain: Brief overview*

The supply chain for the room air conditioner market is very complex and it involves a number of national and international stakeholders (manufacturers, suppliers, consumers etc.). A generic supply chain for the RAC market has four major components and it is depicted in the figure below:

1. Components manufacturers & Suppliers
2. AC manufacturers & Suppliers
3. Wholesalers/ Retailers/Distributors
4. End users

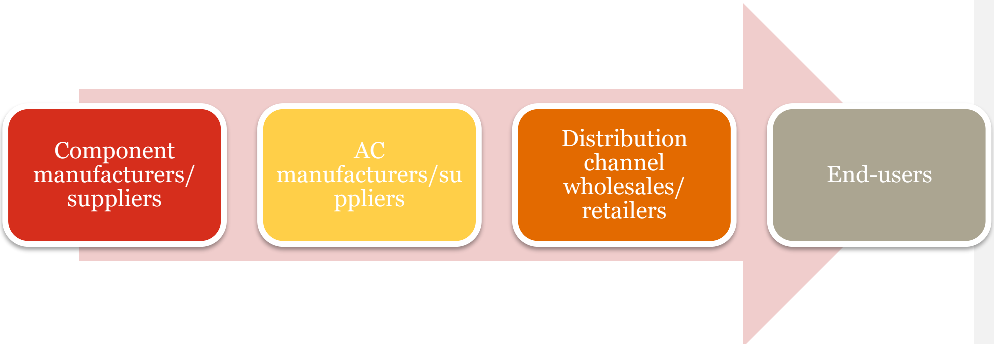


Figure 20 : Simple AC supply chain

An air conditioning system consists of a number of components that need to be configured to manufacture a room air conditioner with desired specifications. As the Figure 20 shows, these components are assembled by the AC manufacturers/suppliers into an air conditioner unit, which reaches the customer through retailers and other distribution channels. Some of the components of an air conditioner are imported from foreign markets while others are either manufactured in-house or procured locally. Similarly, there is an import and export of complete manufactured RACs. The national and international linkages in the air conditioner supply chain structure are discussed in detailed in the next section.

6.2.2 Overall national- international AC supply linkages

The supply chain network of room air conditioner market in India is an amalgamation of national as well as international manufacturers/suppliers. Interactions with manufacturers established that many of the components and assembled RACs (by some companies) are imported from international markets. These linkages are well represented at

Figure 21.

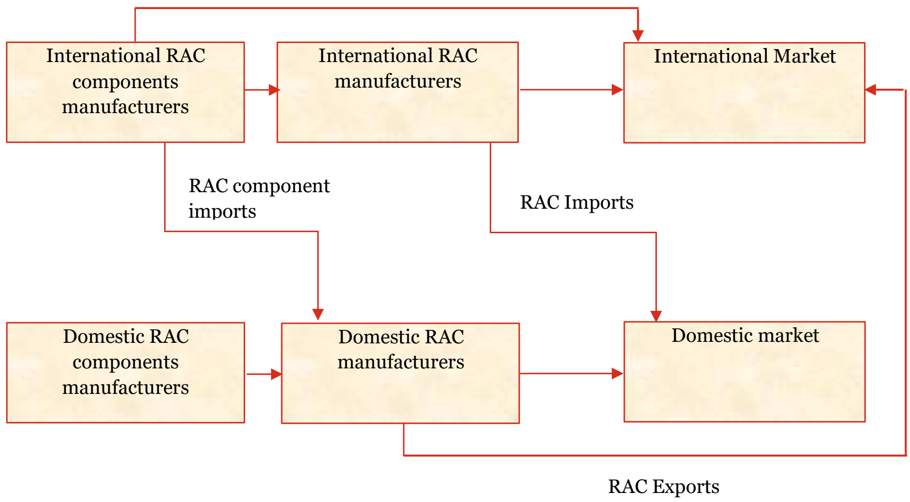


Figure 21 : RAC supply chain linkage - national & international

Figure 21 suggests that RAC manufacturers in the Indian market, not only manufacture different components in-house in their facilities, but also procure them from local as well as global vendors. Components such as compressors are imported from foreign markets by many manufacturers in the domestic market, while heat exchangers are either manufactured in their facilities or procured from local OEMs. In many cases, it is prevalent that the suppliers in the domestic market import all the components of the air conditioners from global vendors and assemble them in their domestic facilities before selling them to distributors/end users. In other cases, some components are imported from abroad while the rest of them are either locally procured or built in-house, and the assembly is sold in the market. Complete RAC is sold in domestic market as well as exported to South East

Asia, Middle East and Africa. The individual components are used to support only domestic manufacturing of air conditioners and are usually not exported.

It has been observed that most of the manufacturers are importing complete IDU units for split air conditioners, while very few import complete air conditioners. The assembled/manufactured air conditioner units reach the consumers in domestic market through a chain of national, regional distributors and retail markets. One of the reasons for importing IDU is overall economics to decide between in-house manufacturing vis-à-vis imports as it is cheap to get it from China, where the scale of production is very high in comparison to produce these units in India keeping in view the market penetration.

6.2.3 National RAC supply chain

After looking at the overall national and international linkages, complete supply chain targeting individual components to supplying assembled RAC to end consumer was also assessed. The detailed supply chain framework is presented at

Figure 22. This has been developed based on consultations with various manufacturers and other experts.

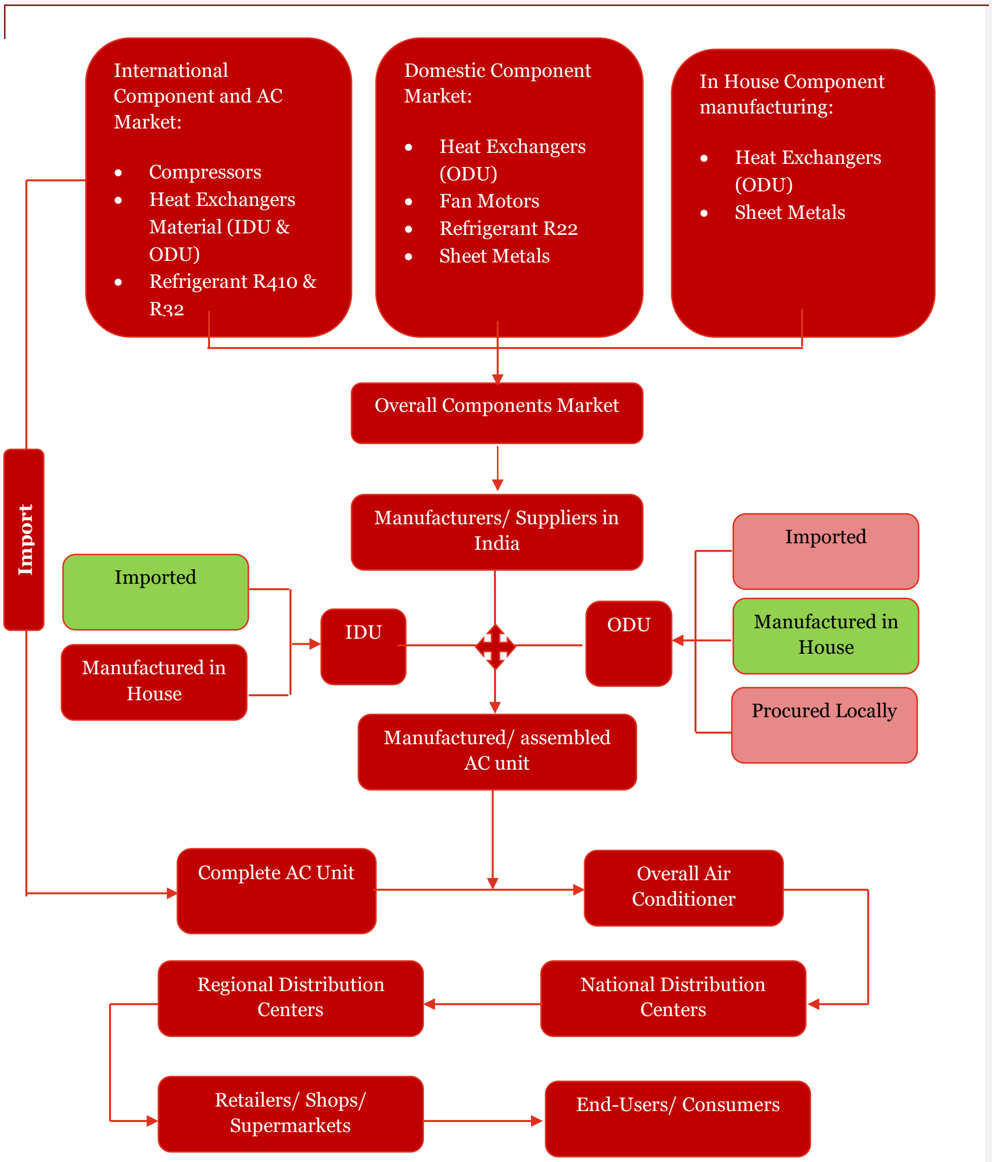


Figure 22 : RAC supply chain

Figure 22 explains the complete component wise supply chain of a room air conditioner at a national level. Interactions with stakeholders (component manufacturers) have revealed that the Indoor Units (IDUs) for air conditioners are being imported by most of the manufacturers in Indian market while the Outdoor Units (ODUs) are primarily being manufactured in-house followed by imports/local procurement. The analysis of the component-wise data reveals that compressors are imported by most of the manufacturers in India. The in-house or local manufacturing of compressors is not prevalent at a large scale in the Indian RAC market. Heat exchangers for the indoor unit of the air conditioner (IDU) are generally imported from international markets, while those for outdoor unit are procured from domestic markets or manufactured in-house. Most of the AC brands use R22 refrigerant which is being manufactured locally by manufacturers. Some AC brands have also started using R410a and R32 as a replacement for R22 and they are currently being imported from global vendors. Fan motors for both indoor and outdoor units are procured from local vendors. Components such as sheet metal are either procured from local market or manufactured in-house. These observations after stakeholder interactions have been compiled in the Table 16:

Table 16 : Status of RAC component manufacturing in India

S.No.	Components	Local manufacturing	Imports	Remarks
1.	Compressor	√	√	Only two manufacturers Tecumseh and Highly have their facilities in India for RAC segment. Rest all are importing.
2.	Heat Exchanger	√	√	Most of the heat exchangers for ODU are either manufactured in house or procured from local OEMs. Most of the companies are importing IDUs from international vendors.
3.	Refrigerant	√	√	R22 refrigerant is manufactured locally. But refrigerant like R410A and R32 are imported.
4.	Fans and fans motor	√	X	These are mainly procured from local vendors. DC motors used by very few manufacturers are imported.
5.	Sheet metal	√	X	These are mainly manufactured in-house or procured from local markets

To further substantiate the findings regarding the supply chain of room air conditioners, the manufacturing of RACs was discussed with manufacturers. It was found that most of the manufacturers have manufacturing facilities in the country, while very few rely on import of complete air conditioner units from abroad to carry out their operations. Table 17 presents the data regarding manufacturing units for some of the leading manufacturers/suppliers, with whom the team could interact during the stakeholder interaction. This information is indicative in nature and is based on the stakeholder interaction.

Table 17 : Manufacturer wise RAC manufacturing facility in India

S.No.	Manufacturers	Room Air Conditioner segment		
		Manufacturing Facility		
		Yes/No	Location	
1	Daikin	Yes	Neemrana	IDU
2	Samsung	Yes	Chennai	IDU
3	Hitachi	Yes	Ahmedabad	IDU

4	Voltas	Yes	Rudrapur	Complete AC Unit [28]
5	LG	Yes	Pune	IDU
6	Panasonic	Yes	Jhajjar	IDU
7	Carrier Midea	Yes	Rajasthan	IDU
8	Blue Star	Yes	Thane	-

The data from the Table 17 shows that all the AC manufacturers have in-house manufacturing facilities in the country.

Some Facts:

The room air conditioner market in India is largely dominated by Indian, Japanese and Korean brands. Most of these manufacturers, are importing complete IDUs and components such as compressors from international markets. Indian manufacturers, such as Voltas, import these components from markets, viz. China and Thailand, where these components are manufactured in bulk using the state-of-the-art technologies. Japanese and Korean brands import these components both from their own facilities in their native markets as well as from Chinese and Thai markets.

Major reason for import of AC components:

The major reason for import of components especially compressors are non-availability of compressor manufacturing facility in India to meet Indian market requirement. There are facilities, which cater to only 15-20% of the overall market and rest all is imported from other countries. Regarding complete RAC units, most of the manufacturers are producing in house and have very limited reliance on imports. The basic reason for this is that they have established their facilities and managed cost economics. At the same time, in case of inverter ACs, manufacturers are importing complete RAC units from other countries. As the product is establishing in Indian market, they are simultaneously working to have in house facilities for this product.

[28] Some part of overall requirement is imported to balance economics of manufacturing. This is manufacturer's own decision to manage their economics.

7 Techno-economic analysis

7.1 'Market Operating Price' for Air conditioners

Commented [NKS1]: Is this different from retail price? If so it should be clearly defined and the difference between MOP and retail price should be outlined. If not, then this should be changed to retail price.

The 'Market operating price' (MOP) presents the actual cost of appliances to the consumers. This section provides a detailed scenario of the market operating prices for different brands of air conditioners in different energy band/star rating categories. The information is limited to 1.5 Ton ACs as it constitutes more than 60% of the RAC market.

The information has been gathered for the two segments: Split AC and Window AC. The market operating price and energy rating data has been collated from market survey/manufacturer's website/product brochures. The following table provides the list of major brands in the Indian market.

Table 18: List of manufacturers of Split and Window AC

Sr. No.	Split ACs	Window ACs
1	Voltas	Voltas
2	LG	LG
3	Samsung	Whirlpool
4	Videocon	Onida
5	Whirlpool	Hitachi
6	Onida	
7	Haier	
8	Midea	
9	Vesta	
10	Panasonic	
11	Hitachi	
12	Daikin	
13	ETA General	

During the FY 2013-14, the manufacturers listed in the

Table **18** above constituted more than 85% of total RAC market (both SACs and WACs) by sales. Thus, these manufacturers, collectively, can be assumed to fairly represent the entire RAC market.

The data extracted/received includes star rating vis-à-vis EER of the air conditioner, and market operating price of the base model of respective brand. Based on the analysis of overall data, an average value of market operating price has been calculated for EER against each star rating band as presented below:

Table 19: MOP – Split AC and Window AC – Each star rating

Star Rating	Split ACs		Window ACs	
	Average EER (W/W)	**[29] - Average Price (INR)**	**Average EER (W/W)**	**- Average Price (INR)**
1	*Data Not Available*		*Data Not Available*	
2	2.9	28850.00	2.7	25740.00
3	3.1	31473.75	2.9	27225.00
4	3.3	36600.00	3.1	30500.00
5	3.5	39684.00	3.3	31475.00

Note: Data for existing one star ACs/equivalent EER level (2.7) is not available in the public domain indicating that one star models are no longer manufactured and sold in the market.

[29] Market Operating Price – MOP of base models of different brands are considered to arrive at the average price for each efficiency level (star levels) for both split and window ACs. MOP's of each star levels were extracted from the field survey.

7.2 Cost breakup Analysis

After the market and technical analysis, information was collated for costing of different components influencing energy efficiency in room air conditioners. The analysis was only possible through interaction with component suppliers/manufacturers and AC suppliers/manufacturers. The figures given below are not exact yet appropriately indicative of the relative costs of different components. Interaction with the various air conditioner component manufacturers suggests that total bill of material cost for a typical 1.5 ton fixed speed air conditioner (ODU) ranges between INR 7000-8000[30] and indoor unit ranges between INR 1700-2100 The approximate cost of different components is presented in Table 20 and their percentage contribution to overall cost is presented in

.

Table 20: Component wise cost break up of manufacturing cost of ODU in RAC (INR)

Components	Component cost (Base) in INR
Compressor	3400 – 3600
Heat Exchanger	1500 – 1700
Sheet Metal	1200 – 1500
Fan blade	200-400
Fan Motor	450 – 600
Refrigerant	300 – 400
Heat Exchanger (IDU)	1200-1500
Fan Motor (IDU)	500-600
Others[31]	2000 - 2500
Total (Excluding Taxes)	10750 – 12800

The analysis of the data shows that the compressor is the biggest contributor to the cost of an air conditioner.. Other important components in an air conditioner from the manufacturing cost perspective are the heat exchangers and sheet metal. Together, these three components, compressor, heat exchanger and sheet metal, constitute 60% of the total cost of an AC.

Any change in the cost of these three components will substantially impact overall cost of air conditioner.

[30] Cost of baseline models (1 to 2 star air conditioner)
[31] It includes installation kit (Connecting pipe, remote control, Instruction manual etc.), connecting wire, sensors, electrical, packing material,

7.3 *Component wise incremental cost analysis*

Energy consumption in air conditioner is dependent on efficiency/performance of its key components. Based on the interaction with manufacturers, various components are ranked in order of their impact on overall energy consumption of an air conditioner.

Table 21: Impact of components of room AC

S.No.	Component	Ranking (Impact)
1.	Compressor	1
2.	Heat Exchanger	1
3.	Refrigerant	2
4.	Fan motor	2
5.	Fan blade	3

It can be inferred from Table 21 that compressor and heat exchanger are the high impacting components followed by Refrigerant, fan motor and fan blade.[32] Following sections present increment cost benefit analysis for different air conditioner components.

7.3.1 *Compressors*

Compressors are the major energy consuming component in the air conditioning system. It's basically a mechanical device which is used to transfer the refrigerant between the evaporator and condenser coil. The compressor functions with the help of the electric motor and compresses and transfer the low vapor refrigerant from the evaporator to the condenser.

7.3.1.1 *Types of Compressor*

Selection of compressor depends on the type of cooling system such as unitary system, chiller system or ducted unitary system. As the target category is unitary air conditioner, this report mainly focuses on categories catering residential and light commercial segment. Following three types of compressors are used globally by air conditioner manufacturers.

1. **Reciprocating Compressors**

In reciprocating compressor, the low pressure refrigerant enters through the suction valve and is positively displaced by the piston cylinder assembly which in turn decreases the volume and increases the pressure of the refrigerant vapor. This high pressure refrigerant then exits from the discharge valve of the compressor.

Compression of the refrigerant through reciprocating system is a decade old technology. Nowadays these systems are rarely used. Only very few manufacturers such as Voltas and other local brands use these types of compressor. Market of this category of compressors is diminishing and these categories are only available in low cost air conditioners.

[32] As such, the author rates heat exchanger's impact slightly higher than compressor.

2. Rotary Compressors

Rotary compressors are mostly used in unitary air conditioners. These are an upgraded version of the reciprocating compressors wherein compression is created through refrigerant from the rotary system as against the reciprocating system where refrigerant is compressed through positive displacement.

In these compressors, low pressure refrigerant vapor is compressed into the high pressure vapor with the support of roller inside the cylinder and the spring mounted blade. Rotary compressors mainly come in air conditioners up to 2 ton of capacity.

3. Scroll Compressors

Scroll compressors are new, advanced technology compressors used for relatively higher capacity room air conditioners (RAC) units. In the Scroll compressors, two scrolls rotate on the same axis and are thus able to reduce the volume of the refrigerant vapor.

Scroll compressors mainly come in above 2 ton category of air conditioners. Manufactures are planning to launch scroll compressors for residential air conditioners but this will take another two or three years as scroll compressors are expensive compared to rotary compressors.

7.3.1.2 Compressor design boundaries

Our understanding of the compressor design suggests that compressor is mainly designed for following three design conditions as presented in Table 22.

Table 22: Compressor design boundaries

Temperature	Remarks
<35	Compressors mainly made for European, Australian, US and other countries
35-38	Compressors made for Indian conditions. The compressors sold in India are made for these conditions.
>46	Compressors designed for Middle East country requirements where the temperature reaches close to 50.

7.3.1.3 Major manufacturers of Compressor

Compressor manufacturing capacity is dependent on market requirements. The cost economics of compressor facility is driven by volume of production and requires huge investments. In view of this, it becomes very difficult for local players to compete with global manufacturers, having huge volume of production. This allows global players to invest on Research and development and produce/sell efficient compressors at competitive cost in the market.

The compressor industry in India is mainly driven by global players followed by participation of few local manufacturers. This industry is characterized into following three categories.

Table 23: Compressor industry categorization

International		National
Manufacturer's own facility	**Independent compressor manufacturers**	
LG *(Compressor from their Korea facility)*	Highly	Highly *(Have set up a facility at Ahmedabad in India and manufacturing small quantity for market. Plan to enhance the production in future as per market requirement)*
Panasonic *(Their compressors from Sanyo)*	GMCC	Tecumseh
Daikin *(Daikin Japan)*	Danfoss	
	Emerson	
	SIAM	

The supply chain of compressors for RAC segment in India at Figure 23:

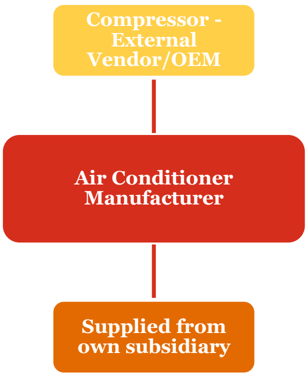


Figure 23 : RAC compressor – supply chain

As evident from Figure 23, some of the air conditioner manufacturers have their own brand compressors such as LG, Panasonic and Daikin which are procured from their own global facilities or from other global compressor manufacturers.

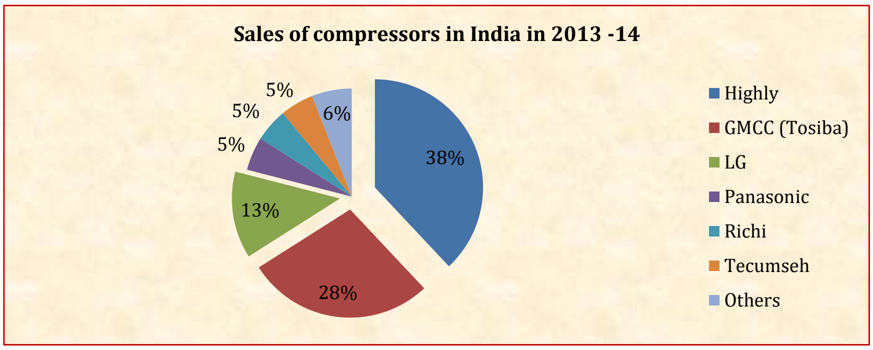
Although Compressor market in India is mainly covered by imports, few manufacturers like Highly and Tecumseh have their manufacturing facilities in Ahmedabad and Hyderabad, but they are producing small quantities.

7.3.1.4 Market share of compressor manufacturers

As discussed earlier compressors are mainly imported and assembled by the manufacturers in their manufacturing facility or through sub-contractors. The market share of major compressor manufacturers is given at Table 24:

Table 24: Compressor manufacturers market share (2013 -14)

S No.	Manufacturer	Capacity (unit)	Imports	Local manufacturing
1	Highly	1254000	Rest all is import	100000(Approx.)
2	GMCC (Toshiba)	924000	100%	Nil
3	LG	429000	100%	Nil
4	Panasonic	165000	100%	Nil
5	Tecumseh	165000	Nil	100%
6	Rechi	165000	100%	Nil
7	Others (Danfoss, Emerson, SIAM etc.)	198000	100%	Nil



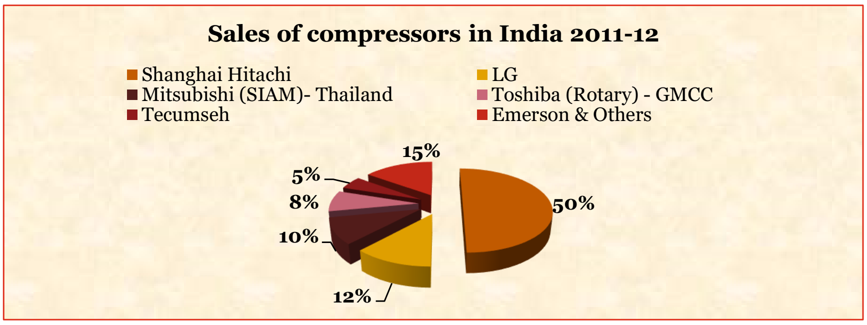


Figure 24 : comparison of sales of RAC compressor in 2011-12 & 2013-14

The analysis for 2013-2014 data suggests that Highly is the market leader for compressors followed by GMCC, having 28% market share. The analysis of 2013-2014 trends in comparison to 2013- 2014 date shows that GMCC has invested lot of efforts to increase its market share from8% in 2011-2012 to 28% 2013-2014. One of the reasons for this is investment by GMCC to provide energy efficient compressors at very competitive price. GMCC could only do this because of its large volume of production. This was also confirmed by different manufacturers. This shows the price sensitivity market behavior moving more towards least cost compressors.

7.3.1.5 Understanding compressor terminology

In order to understand the compressor market in India, interacted with various local and few international compressor manufacturers that are supplying compressors in the Indian market. Following is the list of manufacturer interacted over the course of project.

- ***LG***
- ***Highly (Shanghai Hitachi)***
- ***Emerson***
- ***Danfoss***
- ***SIAM***
- ***Tecumseh***

Key takeaways from analysis of compressors based on secondary research and consultation are presented below:

- Most of the compressors used for up to 2 ton air conditioner category are rotary compressors.
- Scroll compressors are used for air conditioner having 2T and higher cooling capacity. Emerson is coming out with Scroll compressors for 1.5 T categories.
- Compressor design changes depending upon the type of refrigerant used in the air conditioning system.
- Design/Size of the condenser plays a significant role in the selection of the compressor.
- Coefficient of Performance (COP) of the compressor is mainly defined as per ASHRAE standards although few countries such as China and Japan defines compressor COP as per their own standards. It is very important to compare COP of compressors considering same standards.
- Most of the compressors sold in the Indian market have a COP range from 3.0 to 3.4 as per ASHRAE standard.

Snapshot of Few compressor models

Compressor models of few compressor manufacturers were also covered to understand availability of different models in the market. It is interesting to note that for each cooling capacity, few models can cater to the requirement of 1 to 5 star ACs (say for example for a 1.5 ton AC, 1 to 5 star can be achieved by two to three compressor models, similarly for 1 ton AC again two to three models can cater to the requirement of 1-5 star) for each manufacturer, which points that for moving from one efficiency band to another efficiency band, these are the only options.

Snapshot of models of few manufacturers is presented at Table 25. The analysis shows that as such, Highly have models in 1T, 1.5 T and 2.0 T categories, Emerson and Danfoss are having models for only 2T category.

Table 25: Compressor models of manufacturers

S No.	Air Conditioner	Highly	Emerson	Danfoss
1	1 Ton	SL211RY		
2	1 Ton	SL193UY		

3	1.5 Ton	SH295RY		
4	1.5 Ton	SH286UY		
5	2 Ton	SH380RY	23700	HRM042
6	2 Ton	SH370RY	25700	HRM060
7	2 Ton	SH356UY	27500	HLM072

7.3.1.6 Compressor shift and Incremental cost benefit analysis

Analysis of compressors being used by different manufacturers suggests that manufacturer use 2 to 3 types and size to move from EER of 2.7 to EER of 3.5. Most manufacturers use same type and size of compressor to achieve EER up to 3.1 in each cooling capacity. For higher EER, they use more efficient model. The compressors are selected based on two important parameters viz. frame size and COP desired by the air conditioner manufacturer. Frame size is the chassis of the condenser unit, which ultimately decides the COP desired from compressor. Based on discussions with compressor manufactures, the applicability of compressors for different star rating categories, frame size is presented at Table 26. The analysis also captures incremental cost for different efficiency compressor models. [33]

Table 26: Compressor incremental cost for 1.5 Ton AC

Parameters	2.7 EER	2.9 EER	3.1 EER	3.3 EER	3.5 EER
AC Capacity (Ton)	1.5				
AC Frame Size (Inch)	20"	20"	22"	24"	24"
Compressor COP (as per ASHRAE)	3	3	3.2	3.4	3.4
Compressor Cost (USD)*	**62.0**	**62.0**	**65.0**	**68.0**	**68.0**

*Cost charged to air conditioner manufacturer excluding taxes

Key takeaways from the analysis are presented below:

- One size and type of compressor can be used to achieve EER up to 3.1 while the frame size/chassis size of air conditioner change when we move beyond 3.1 EER. To achieve EER of 3.1, few manufacturers are using compressors of 3.2 COP, which cost around USD 65.0 i.e. an increment of USD 3.0 from compressor of COP 3.0.

- Average cost of compressor of 1.5 ton AC is close to USD 62.0 excluding taxes and may vary up to USD 68.0 for higher EER. As per supplier and manufacturers the tentative cost of other parameters such as taxes, transportation etc. would be around USD 3.0.

- Improving the EER by one level, compressor is not the only option and there are other methods to improve system efficiency.

[33] The costing of compressors is derived based on informal discussions with compressor manufacturers. It may change based on the actual data.

- Compressor with highest COP of 3.4 is currently available in India and are used by the manufacturers for AC's with EER of 3.3 and above. The cost of compressor of 3.4 COP is about USD 68.0, thereby suggesting an incremental cost of USD 6.0 to move from EER of 2.7 to 3.5 and above.
- Similar analysis is carried out for 1 and 2 ton air conditioners and the summary of which is given at Table 27:

Table 27: Compressor incremental cost for 1 Ton AC

Parameters	2.7 EER	2.9 EER	3.1 EER	3.3 EER	3.5 EER
AC Capacity (Ton)	1				
AC Frame Size (Inch)	20'	20'	22'	24'	24'
Compressor COP	3.0	3.0	3.2	3.4	3.4
Compressor Cost (USD)*	**52.0**	**52.0**	**55.0**	**58.0**	**58.0**

*Cost charged to air conditioner manufacturer excluding taxes

The incremental cost of the compressors for 1 ton air conditioners usually ranges from USD 52.0 to USD 58.0 with an additional USD 3.0 for taxes and other transportation costs.

Table 28: Compressor incremental cost for 2 Ton AC

Parameters	2.7 EER	2.9 EER	3.1 EER	3.3 EER	3.5 EER
AC Capacity (Ton)	2				
AC Frame Size (Inch)	22'	22'	24'	26'	26'
Compressor COP	3	3	3.2	3.4	3.4
Rotary Compressor Cost (USD)*	72	72	75	79	79
Scroll Compressor Cost (USD)*	110.0	110.0	115.0	120.0	120.0

*Cost charged to air conditioner manufacturer excluding taxes

The analysis for 2 ton capacity suggest that, both rotary and scroll compressors are used. Scroll compressors have high volumetric efficiency as compared to rotary compressors and they are used for 2 ton and above category air conditioners.

Also the price of scroll compressors varies from USD 110.0 to US 120.0 for moving from EER of 2.7 to EER of 3.5 against price of USD 72.0 to USD 79.0 for rotary compressors. It is therefore costlier to use scroll compressors.

Compressors to achieve next level of efficiencies

The following two factors predominantly influence energy efficiency improvement through compressors.

- Is compressor the preferred option to move to next levels of efficiency
- Is compressor with COP > 3.4 available in India

The cost benefit analysis for compressor efficiency gain is presented in Table 29:

Table 29: Cost benefit analysis - compressor

S No.	Ton	Type of Compressor	Particulars	Compressor				
							+ 1 level of efficiency	+ 2 level of efficiency
			COP	3.0	3.2	3.4	3.6	NA
				0.2	0.2	0.2		
			Price (USD)	52	55	58	68-80	NA
				3	3	10		
			COP	3.0	3.2	3.4	3.6	NA
				0.2	0.2	0.2		
			Price (USD)	62	65	68	78-90	NA
				3	3	10		
			COP	3.0	3.2	3.4	3.6	NA
				0.2	0.2	0.2		
			Price (USD)	72	75	79	88-100	NA
				3	3	10		
			Price (USD)	110	115	120	135	
				5	5	15		

The analysis and stakeholder consultation suggests that *there are compressors with COP of 3.6 and 3.8 available in European market. LG is selling these products in European market***.** These compressors are not available in the Indian market due to the higher cost as these are usually USD 10.0 to USD 15.0 costlier as compared to conventional compressor of COP 3.4. *Selection of Compressor is dependent on pricing and to move beyond EER of 3.5, manufacturers may not consider using compressor of COP>3.4 as first option but* may work on heat exchangers and other components to achieve higher efficiencies.

7.3.2 *Heat Exchanger*

Heat exchangers is another important component in the air conditioning unit and is meant to transfer heat from inside to the ambient and thereby cooling in the air conditioning space. Heat exchanger finds application in air conditioner in following two ways.

- Evaporator
- Condenser

Heat transfer in air conditioner happens in two ways i.e. conductive heat transfer and convective heat transfer. The schematic of heat transfer stages is presented in figure 26.

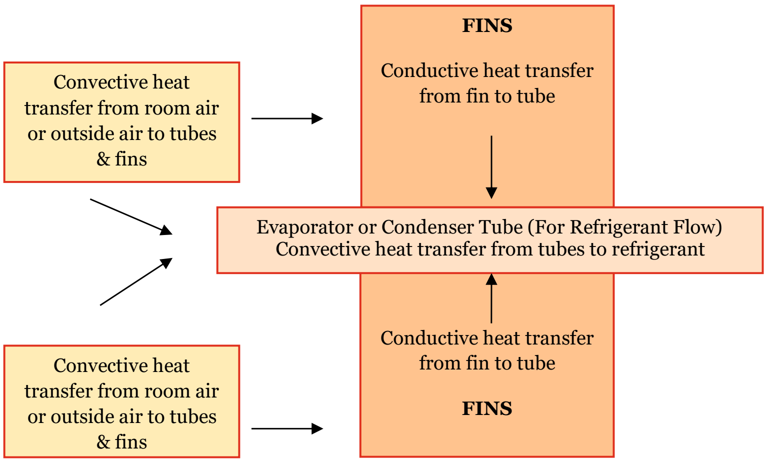


Figure 25 : Heat transfer mechanism in Heat Exchangers of an AC

The efficiency of a heat exchanger drives the efficiency of overall air conditioning unit and are dependent on following important variables.

- Area of heat exchanger
- Material of heat exchanger

Heat transfer in an air conditioner is defined by following equation.

$Q=U*A*\Delta T$

Q = Overall heat transfer

U = Overall heat transfer coefficient

A = Area of heat exchanger

ΔT =heat gain or lost

By improving overall heat transfer coefficient or increasing the heat transfer area, overall heat transfer can be increased, thereby improving the efficiency of air conditioner.

Increasing overall heat transfer coefficient (U)

Overall heat transfer coefficient can be achieved by following measures.

- Use of better materials
- Fin design & configuration
- Air flow designs in air conditioner

Increasing heat transfer area (A)

Heat transfer area can be increased following measures.

- Increasing number of tubes
- Working on diameter of tubes
- Increasing number of passes
- Putting fins

7.3.2.1 Types of heat exchanger

Heat exchanger comprises of Condenser and Evaporator section. In case of split air conditioners, condenser is part of the Outdoor unit (ODU) while evaporator is part of Indoor unit (IDU). In case of windows air conditioners, condenser and evaporator come under same housing.

There are three types of heat exchanger that are commonly used by RAC manufacturers;

1. **Copper Tube – Aluminum Fin (CTAF)**

   CTAF are the commonly used heat exchangers in RAC segment. In this type of heat exchanger, the tubes are made of Copper and Fins are made of Aluminum.

2. **Aluminum Tube – Aluminum Fin (ATAF)**

   ATAF are rarely used these days owning to its less durability as compared to CTAF. This type of heat exchangers are prevalent only in very few air conditioner models and has significantly lost its importance.

3. Brazed Aluminum Micro-Channel

This is newly developed technology that has been adopted from automobile sectors, where it is operating successfully. In last few years, Indian RAC manufacturers have considered this option as a replacement to CTAF heat exchangers. In this heat exchanger, multiple micro tubes having small diameter are used to transfer refrigerant. The heat exchanger is then supported by very large matrix of fins which increase the surface area of the heat exchanger.

The comparison of different types of heat exchanger is given at Table 30.

Table 30: Heat exchanger comparison

S No.	Parameters	ATAF	CTAF	BAM
1	Heat Carrying Capacity	Less dense compared to copper, thus heat carrying capacity less compared to copper.	Heat carrying capacity almost 3.3 times that of ATAF. Good option for better heat transfer.	Heat carrying capacity is similar to CTAF & sometimes it is even more than CTAF
2	Space requirement	Less space requirement due to less density compared to CTAF	More space requirement compared to ATAF	Almost 25-30% less space requirement compared to CTAF for same heat transfer capacity.
3	Corrosion problems	It is not prone to corrosion. Thus better compatibility with all refrigerants.	These are very prone to corrosion. Thus needs extra galvanizing for protection against corrosion.	These have some design constraints but are less prone to corrosion & thus are suitable for all types of refrigerants.
4	Strength	Less strength as compared to CTAF.	Excellent strength	Less strength in comparison to CTAF, which is its main limitation?
5	Impact on system Power consumption	Normal power consumption	More consumption by fans due to more refrigerant capacity & system density	More heat transfer in same area thereby increasing cooling capacity and improving EER.

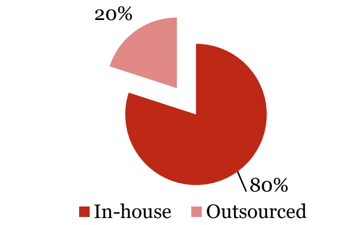
7.3.2.2 Major manufacturers of heat exchanger

Most of the air conditioner manufacturers import complete IDU from other countries mainly from China. So evaporators are mainly not manufactured in India and they come as part of complete IDU. The analysis in this report is only with respect to the condenser units of air conditioner. The supply chain analysis of this market suggests that condenser units are either manufactured in house by air conditioner manufacturer or they are procured from OEMs as single unit or complete ODU. The analysis points that 80% of condenser manufacturing is done in-house by manufacturers and they outsource 20% of the overall requirements from OEMs.

Major OEMs that are supplying heat exchangers to air conditioner manufacturers are presented below:

- Lloyd Electric
- Amber
- Spirotech

Figure 26 : Manufacturing of condenser Heat exchanger



A brief about the design and construction process of heat exchangers and industrial nomenclature for condenser heat exchangers has been detailed in **Annexure-2.**

7.3.2.3 Incremental cost benefit analysis

As discussed above, CTAF and BAM are the two majorly used condenser heat exchangers in the Indian market. Discussions with manufacturers were made to assess the market preference for. Key takeaway from the assessment of the market preferences of heat exchangers are presented below:

- BAM heat exchangers have gained acceptance amongst manufacturers as a replacement option for CTAF. But discussions suggested that there are serviceability issues with BAM, which need to be addressed. Few manufacturers have been giving warranty on BAM heat exchangers, if damaged.

- One of the important trends shared by manufacturer is that few manufacturers are coming back to CTAF and are planning to sell CTAF air conditioners as premium products and plan to charge more as compared to BAM based air conditioners.

- Manufacturers see BAM as one of the option to achieve higher/next level of efficiencies as it is more cost effective as compared to CTAF.

1. **Improving the efficiency through CTAF heat exchanger**

   The changes made in heat exchanger of AC's of EER of 2.7 to higher EER and the associated incremental cost is presented at Table 31.

Table 31: Energy efficiency vs. cost incremental - CTAF

Parameters	2.7 EER	2.9 EER	3.1 EER	3.3 EER	3.5 EER	+ 1 level of efficiency	+ 2 level of efficiency
AC Capacity	1.5						
Type of HX	CTAF						
No of Row (R)	1	1.4	1.7 - 2	3	3		
Area (A)	A	A+40%A	2A	3A	4A		
HX Cost (INR)	1250	1500	12200	3000 + @25 % increase in Chassis cost	4200		

Moving from 3.1 to 3.5 EER increases chassis size thus increasing cost by 25%.

To move beyond 3.5 EER, chassis size need to be increased again with increase in HX area. (Not viable)

2. **Improving the efficiency through BAM heat exchanger**

Table 32: Energy efficiency vs. cost incremental - BAM

Parameters	2.7 EER	2.9 EER	3.1 EER	3.3 EER	3.5 EER	+ 1 level of efficiency	+ 2 level of efficiency
AC Capacity	1.5						
Type of HX	BAM						
No of Row (R)			1	1.2 – 1.4	1.7 – 2	Bet. 2-3	Almost 3
Area (A)			A	Not much sale	A+20%A	A+50%A	Almost 2A
HX Cost (INR)			1500	1500	2200	3500 + Incremental gain in Chassis cost	4200-5000

Through Option 2, manufacturer may target to achieve higher efficiency.

7.3.2.4. Key Take Away

The observations and comparison between CTAF and BAM cost benefit analysis:

Table 33: Performance comparison between CTAF and BAM

CTAF HX	BAM HX
• It is possible to improve the EER from 2.7 to 3.1 by increasing the area of heat exchanger by twice without changing the chassis size. This can be achieved by increasing the tubes. The tentative cost of condenser unit for EER 2.7 is INR 1250 and it increases to INR 1800 to achieve EER of 3.1. • For moving beyond EER 3.1, it is not possible to work on same chassis size. Thus moving beyond EER of 3.1, there is increment in condenser cost plus 25% increase in Chassis cost. • For moving beyond EER of 3.5, chassis size will need to be increased again, which may not a feasible option due to size as well as cost constraints.	• Manufacturers start using BAM for EER above 3.1. • It is possible to achieve EER 3.1 to EER 3.5 by increasing the area of micro channel with same Chassis size • The cost of BAM for EER 3.1 AC is INR 1500 against the cost of INR 1800 plus 25% chassis cost for CTAF. Therefore, manufacturers are preferring BAM as an option to move towards higher efficiencies. • For moving beyond EER 3.5, chassis size will need to be increased again, which will incur an increment in cost, although a feasible option but there are *serviceability issues and needs serious due diligence.*

7.3.3 Refrigerant

Refrigerant is a medium of heat transfer medium in an air conditioner to provide cooling. The choice of refrigerant is very important in driving energy efficiency and environment program in any country to reduce greenhouse gas emissions. Refrigerant selection can impact environment in following two ways;

- **Direct global warming** – This impact may take place because of refrigerant leakage from the system. Refrigerant containment in the system is key to reduce this impact. With the advent of low global warming potential (refrigerants) less than 4000 GWP this impact has been controlled and is less than 5% of overall warming impact.

- **Indirect global warming** – This impact covers close to 95% of the overall warming impact**.** In an air conditioning system, this impact is a dependent on compressor type and its efficiency, system design and heat transfer properties of the refrigerant.

Policies to improve efficiency of air conditioners/refrigerants lead to reduction in indirect global warming.

7.3.3.1 Key components of refrigerant selection

Selection of right refrigerant is key to proper design of air conditioners. Following important components help decide right choice of refrigerants.

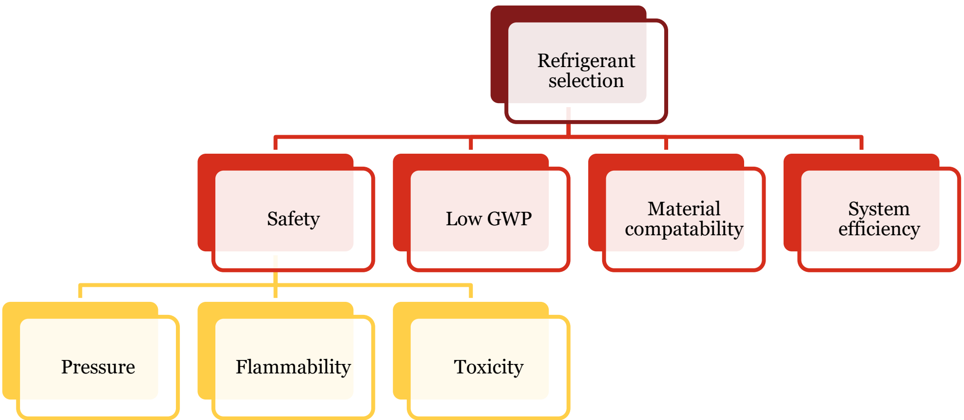


Figure 27 : Components of refrigerant selection

As such all these components are very important in refrigerant selection, but safety plays an important role no matter how good the system efficiency of that refrigerant is. Various components for safety are described below:

Pressure: Operating pressure of refrigerants is very important in the selection of use of refrigerant. Normally high pressure refrigerant would require a completely new designed system for safe operation.

Flammability: This is a very important safety component as leakage of flammable refrigerant may lead to fire or explosion.

Toxicity: This is again very important component to avoid dangerous impacts.

Standard terminology to differentiate refrigerants

Following terminology is being adopted by the industry to rate refrigerants on different safety expects.

Table 34: Terminology to differentiate refrigerants

Toxicity		Flammability	
A	Non Toxic	1	Non flammable
B	Toxic	2	Mild flammable
		L	Low on flammability
		3	Flammable

7.3.3.2 Types of refrigerant used in air conditioners

In last few years, there have been developments from environment front and many refrigerants have been tested and adopted for air conditioning applications considering the present and future requirements. Following are few of the refrigerants that are commonly used in the air conditioning industry in India.

1. R22
2. R 410A
3. R290
4. R32

At present, 80 percent of the manufacturers are using R22 as refrigerant followed by R410A. The component wise analysis of different refrigerants is presented Table 35.

Table 35: Performance comparison between refrigerants

S No.	Group	HCFC	HFC		HC
	Refrigerant	R22	R410A	R32	R290
1	Ozone Depletion Potential (ODP)	0.05 (It has low chlorine content)	0 (No chlorine content)		0 (No chlorine content)
2	Global Warming potential (GWP)	1700	1725		<20
3	Safety (Toxicity & Flammability)	A-1	A-1	A-2L	A-3.
4	Pressure	272	494	Limited information	274
5	Compressor COP	Reference	2-5% more than R22		2-3 % less as compared to R22
7	Pressure drop	Reference	Lower as compared to R22	Less as compared to R22	Same as R22
8	Charge	Reference	10-20% less as compared to R22	20-30% as compared to R22	

9	Cost of charge	6-7$	Slightly expensive as compared to R22	Expensive as compared to R22	Most expensive
10	System performance	Reference	Better as compared to R22	Better but flammable	Claimed efficient**

*Manufacturer discussions and Emerson's research paper

**Godrej has sold close to 50000 air conditioner in market with R290 as the refrigerant.

7.3.3.3 Decision about selection of refrigerants

Following points help manufacturers decide refrigerants to be used in their air conditioners;

- Regulatory push
- Balancing between refrigerant cost savings vs system cost
- Decisions between refrigerant efficiency vs system efficiency
- Impact on tubing and other components
- Infrastructure preparation at manufacturer facility to store/use refrigerants
- Competency to do maintenance of systems

Observations/status of readiness for different refrigerants – Manufacturer's perspective

R22 refrigerant: This is an established refrigerant and close to 80% of the air conditioners manufactured in India are using R22. The import of R22 is banned and its use may be banned in near future. So there is a need to explore alternatives with low GWP, low GHG, and low flammability.

R410A refrigerant: R410A is well established and accepted by many manufacturers as next category/type refrigerant due to its benefits over R22. Most of the inverter air conditioners are already using R410A.

R32 refrigerant: R32 refrigerant has mixed response, although Japanese manufacturers like Daikin, Panasonic claim that it is efficient and safe. There is no clear policy direction and there are Intellectual Property Rights (IPR) issues.

R290 refrigerant: Godrej has sold a substantial number of air conditioners with R290 refrigerant, but there are issues concerning safety. Absence of safety standards in India is also one of the major barriers for its use.

7.3.4 *Fans & fans Motor*

Motor is used to drive fans of both indoor & outdoor units of room air conditioners. Fan motor consumes around 10-12% of the total power consumed by a RAC.

7.3.4.1 *Type of Fan motors*

Generally the manufacturers are using permanent split capacitor (PSC) motors (fixed speed motors) for fans. However, another technology that can also be used for fan motors in room air conditioners is "Electronically Commutated Motors (EMC)- commonly known as Brushless DC motors (BLDC)".

The manufacturers procure fan motors from local motor manufacturers. Some of the manufacturers tried BLDC motors, but stopped using it because of lack of technological knowledge, non-availability of major components and higher production

Detailed analysis of PSC motors and BLDC motors is presented at Table 36.

Table 36: Comparison between fan motors

Parameters	AC constant speed motor (PSC)	Brushless DC motor
Motor Efficiency	40-60%	70-80%
Fan RPM	Higher (around 1100-1700)	Lower than AC constant speed motor (800-1400)
Energy consumption	Maximum. Indoor Units Fan- **50- 60 W** Outdoor Unit Fan- **120-145 W**	Almost half of AC motor Indoor Units Fan- **20- 30 W** Outdoor Unit Fan- **50-60 W**

As such, there are energy benefits with BLDC, but it has some issues, which hinders its use in both IDU and ODU units. The issues with BLDC are presented at Table 37.

Table 37: Operational issues of BLDC motor

Issues	Barriers
Performance against Voltage Fluctuation	Performance is not up to the mark in areas where voltage is not steady like rural households
Maintenance or repairing of motor	Whole motor replacement is necessary after damage to the electronic chip. Availability/training of local repair persons is the requirement, which is again a cost addition.
Power Factor	The power factor of BLDC motor is 0.6 as against 0.9 mentioned in the standard

The cost of BLDC is much higher than normal motors. The cost difference between normal AC motor and BLDC motor is presented at Table 38. As evident, the increment cost for moving from AC motor to BLDC motor is close to 5.0$,

Table 38: Cost comparison between AC motor and DC motor

Air Conditioner Unit	AC Motor	DC Motor
Outdoor Unit	USD 8.0	USD 12.0-14.0
Indoor Unit	USD 7.0	USD 12.0 (Non- replaceable)

Effect on fan motor with increased efficiency of air conditioner

The energy consumption by a fan increases with the increase in efficiency of an air conditioner. As the EER value increases, the air flow requirements of the fan also changes, thereby increasing the fan size resulting in an increase in power consumption of fan motors.

The indirect savings come from air flow in overall system design.

Improving energy efficiency of air conditioner through air flow

An attempt was made to assess the variation in air flow of an air conditioner. As such, detailed information was not available, but limited information gathered from few manufacturers is presented at Table 39.

Table 39: Air flow volume for different AC brands

Brand	Star label	Air flow volume- Indoor (CFM)
	2 star	500
	3 star	500
	5 star	500
	2 star	425
	3 star	530
	4 star	565
	5 star	565

From the table above, it is understood that while in case I, the increase in efficiency has been achieved by not changing the air flow but by any other option, while in another case, the efficiency has been increased by increasing the volume of air flow as one of the options.

Debate still remains whether fan motor or fan contributes significantly to energy efficiency in air conditioners.

7.3.5 Expansion Valves

The expansion valve removes pressure from the liquid refrigerant to allow expansion or change of state from a liquid to a vapor in the evaporator. The high-pressure liquid refrigerant entering the expansion valve is quite warm. This may be verified by feeling the liquid line at its connection to the expansion valve. The liquid refrigerant leaving the expansion valve is quite cold. The orifice within the valve does not remove heat, but only reduces pressure. Heat molecules contained in the liquid refrigerant are thus allowed to spread as the refrigerant moves out of the orifice. Under a greatly reduced pressure the liquid refrigerant is at its coldest as it leaves the expansion valve and enters the evaporator.

Pressure at the inlet and outlet of the expansion valve closely regulates gauge pressures at the inlet and outlet of the compressor in most systems. The similarity of pressures is caused by the closeness of the components to each other. The slight variation in pressure readings of a very few pounds is due to resistance, causing a pressure drop in the lines and coils of the evaporator and condenser.

7.3.5.1 Types of Expansion Valve

Three types of expansion valves are used on air conditioning systems:

1. Capillary Tube Expansion Valves

2. Thermostatic Expansion valve
3. Electronic Expansion Valves

Capillary Tube Expansion Valves[34]:

A small capillary tube connects the high pressure condenser side to the low pressure evaporator side. Capillary tube restricts and meters the liquid flow and maintains the required pressure differential between the condenser and the evaporator. Due to friction, the refrigerant pressure drops as the liquid passes through the restriction. The capillary tube diameter and length must be such that the flow capacity at the design pressures (condensing and evaporating) equals the compressor pumping capacity at these same conditions.

Thermostatic Expansion valve:

The thermal expansion valve is used for refrigerant flow control and operates at varying pressures resulting from varying temperatures. The thermostatic expansion valve needs capillary tube and thermal element (bulb) to work. The capillary tube connects the element to the top of diaphragm. The element (sensing bulb or thermal bulb) is partly filled with a liquid refrigerant (usually the same refrigerant used in the system) and maintains some liquid under all conditions of temperature and load

Electronic Expansion Valves (EEV)[35]:

The Electronic Expansion Valves balance and modulate the refrigerant flow to the heat load by sensing the refrigerant leaving the evaporator. This is done in response to signals sent by an electronic controller. A small motor is used to open and close the valve port. Motors can run at high speeds (~200 steps per second) and can return to their exact position quickly which gives them an accurate control of the refrigerant that flows through them.

Advantages of EEV over Capillary Tube Expansion Valves

- High precision and efficiency over wide temperature and evaporator load range.
- Variation in refrigerant charges can be handled.
- Suppression of less cooling at long piping condition.
- Reduces possibility of liquid slugging by improving the liquid flood back issues, thus protecting the compressor from damage.

The comparison of costing of the different types of expansion valves is shown in table 40 based on the information furnished by the manufacturers

Table 40: Indicative cost of three types of Expansion Valves[36]

Type of Expansion Valve	Indicative Cost (INR)
Capillary Tube	50
Thermostatic	250-300
Electronic	500 - 700

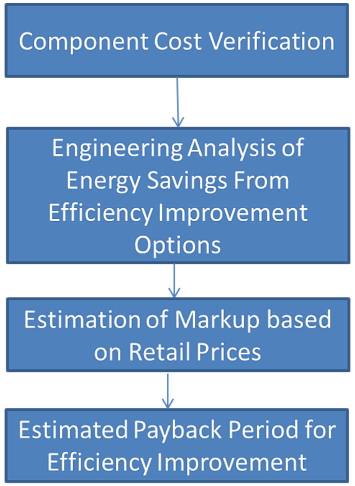
[34] Source: *www.central-air-conditioner-and-refrigeration.com*
[35] Source: *Product brochure, Sharp Corporation*
[36] Source: *Stakeholder Interactions*

Table 40 shows that the cost of an Electronic expansion valve is much higher than a Capillary expansion valve. However, an electronically controlled expansion valve provides more accurate and precise control of the refrigerant as compared to a Capillary tube expansion valve, thereby making it a more efficient alternative. However, it is difficult to quantify the energy savings in an air conditioner due to the use of an Electronic expansion valve.

Most of the manufacturers are using Capillary tube expansion valves because of their lower cost.

8 Engineering Analysis

Improving efficiency of air conditioners (ACs) typically involves improving the efficiency of various key components influencing the energy efficiency such as compressors, heat exchangers, expansion valves, and fans. The incremental cost of improving the efficiency of room ACs can be estimated based on the cost of improving the efficiency of its key components. Further, the retail price increase required to cover the cost of efficiency improvement is estimated by applying suitable markup on the total manufacturing cost and then payback period is calculated for consumers to recover the additional price of a more efficient AC assuming that AC would be as efficient as compared to a new Ac over its period of use. Flow chart given below describes stepwise procedure of engineering analysis.



Although statistical approaches can be used to estimate the price increase due to efficiency alone based on prices observed in the market, however, there are several limitations including the inability to estimate varying profit margins across different brands and product ranges. Further, assessment based on retail prices alone cannot provide estimates of costs of improving the efficiency beyond what is currently available on the market in a certain region or a country.

In this case the engineering analysis uses the methodology and energy savings data for each component developed by the EU Eco-design study (EuP,2009), while using the latest cost data for the components collected and described in the earlier chapters. Table 43 below summarizes energy savings for each component and corresponding increase in Bill of material cost.

It is important to note here that these energy savings numbers for each component are derived from a simulation model used in the EU Eco design study (EuP,2009) calibrated with actual test data and extensively peer-reviewed as part of the EU Eco design standards setting process.

Table 411 Component-wise incremental costs of efficiency improvement for 1.5 ton fixed speed ACs

Component	**Energy Savings from Base Case**[37]	**Incremental Bill of Materials Cost (Rs.)**[38]
Baseline Compressor (2.8 EER), 1.5 TR Cooling Capacity	-	-
3.0 EER compressor	5.5%	₹ 200
3.2 EER compressor	10.5%	₹ 400
3.4 EER compressor	15.0%	₹ 575
3.6 EER compressor	20.0%	₹ 2,000
UA value of both heat exchangers increased by 20%	7.5%	₹ 1,470
UA value of both heat exchangers increased by 40%	13.5%	₹ 3,240
UA value of both heat exchangers increased by 60%	17.5%	₹ 4,210

[37] Energy savings estimates are based on EuP, 2009 energy savings data.

[38] Estimates based on component costs reported in earlier chapters.

UA value of both heat exchangers increased by 80%	21.0%	₹ 6,080
UA value of both heat exchangers increased by 100%	24.0%	₹ 7,350
Thermostatic Expansion Valve	3.5%	₹ 250
Electronic Expansion Valve	6.5%	₹ 700

Based on the component-wise incremental cost data and the energy savings data for the corresponding components presented in the EU Eco-design study (EuP, 2009) and shown in Table 41 above, LBNL constructed a cost versus efficiency curve based on ninety (90) possible design combinations of component efficiency levels (e.g. heat exchangers, compressors and expansion valves) to simulate the lowest cost of improving efficiency of a fixed -speed Room AC at various levels of efficiency improvement. A summary of these design combinations is shown in Table 42 at various levels of efficiency.

The price increase required to cover the cost of efficiency improvement is estimated as:

Price increase required = incremental cost of efficiency improvement*mark-up for a baseline product

As mentioned in table 20, estimated manufacturing cost of a baseline 1.5 Ton Room AC is about Rs. 12,800 and the average retail prices of baseline (1-2 star) models is about Rs. 30,500.[39] Hence the mark-up for base line products in the market is about 140% which means that cost increase of Rs. 1000 to improve efficiency will require a price increase of approximately Rs. 2400 to cover items such as profit margins of manufacturer, distributor, retailer, transportation, advertising and other miscellaneous costs .It is important to note that mark-up for high efficiency models in the market is often higher due to other non-efficiency related features and also because these products are marketed as “premium” products.

Finally, the electricity bill savings due to efficiency improvement are calculated and difference between the base line retail price and the higher efficiency retail price can be compared. Summary of these design combinations as well as the corresponding electricity savings and payback periods are given in Table 42 below.

Table 422: **Least cost strategies to improve room AC efficiency**

[39] Source: Stakeholder consultations

`	Compressor	Heat Exchanger	Expansion Valve	Total Manufacturing Cost (Rs)	Additional Manufacturing Cost (Rs)	Estimated Retail Price (Rs)	Additional Retail price (Rs)	Energy Consumption (kWh/yr)	Power Consumption (kW)	Annual Bill Saving (Rs/yr)	Payback Period (yrs)
2.78	2.8 EER Compressor (Base Case)	Base Case HX	Capillary Tube	12720	#N/A	30528	#N/A	3023	1.82	0	#N/A
3.10	3.2 EER Compressor (Rs 400)	Base Case HX	Capillary Tube	13120	400	31488	960	2705	1.63	2222	0.4
3.22	3.2 EER Compressor (Rs 400)	Base Case HX	Thermostatic Expansion Valve(Rs 250)	13370	650	32088	1560	2611	1.57	2885	0.5
3.39	3.4 EER Compressor (Rs 575)	Base Case HX	Thermostatic Expansion Valve(Rs 250)	13545	825	32508	1980	2479	1.49	3803	0.5
3.50	3.4 EER Compressor (Rs 575)	Base Case HX	Electronic Expansion Valve(Rs700)	13995	1275	33588	3060	2402	1.44	4343	0.7
3.78	3.4 EER Compressor (Rs 575)	UA value of HX increased by 20% (Rs 1470)	Electronic Expansion Valve(Rs700)	15465	2745	37116	6588	2222	1.34	5604	1.2
4.02	3.6 EER Compressor (Rs 2000)	UA value of HX increased by 20% (Rs 1470)	Electronic Expansion Valve(Rs700)	16890	4170	40536	10008	2092	1.26	6519	1.5
4.24	3.4 EER Compressor (Rs 575)	UA value of HX increased by 60% (Rs 4210)	Electronic Expansion Valve(Rs700)	18205	5485	43692	13164	1982	1.19	7286	1.8
4.29	3.6 EER Compressor (Rs 2000)	UA value of HX increased by 40% (Rs 3240)	Electronic Expansion Valve(Rs700)	18660	5940	44784	14256	1956	1.18	7469	1.9

4.50	3.6 EER Compressor (Rs 2000)	UA value of HX increased by 60% (Rs 4210)	Electronic Expansion Valve(Rs700)	19630	6910	47112	16584	1865	1.12	8102	2.0
4.70	3.6 EER Compressor (Rs 2000)	UA value of HX increased by 80% (Rs 6080)	Electronic Expansion Valve(Rs700)	21500	8780	51600	21072	1786	1.07	8656	2.4

Key Findings

Key findings from the market and techno-economic assessment are as follows:

a) Market forecast

- Total RAC market stands close to 3.3 million units (2013-2014), mainly dominated by split air conditioners.
- Major share of manufactured and sale is of 1.5 tons capacity with a market share of 62%.
- There has been a downward trend in the sale of window type AC over the past few years due to which manufacturers are not too keen to invest on the R&D activities for the adoption of new and efficient technologies for this category.
- The sales forecast data show an upward trend, with the expected sale of 7.7 million units by 2020-21. This is also reflected in the market forecast for Indian RAC industry which predicts a 10-13% CAGR growth in the next 5 years.

Supply chain

- There is sufficient capacity in India to produce split as well as windows ACs.
- Most of the manufacturers import IDU for split air conditioners from China, while very few import complete air conditioners. The assembled/manufactured air conditioner units reach the consumers in domestic market through a chain of national, regional distributors and retail markets. One of the reasons for importing IDU is that it is economical to get it from China rather than producing them in India.
- Most of the manufacturers/suppliers import compressors whereas heat exchangers used in ODU are either manufactured in house or procured from local OEMs.

- Most of the Air conditioners sold in Indian market use R22 refrigerant; some of the manufacturers have started using R410A and R32 which are imported. Manufacturers have invested on the manufacturing facilities to change over to R410A. Some of the manufacturers are ready with R32 refrigerant, but majority are having wait and watch policy considering regulatory as well as patent issues.

Efficiency levels sold in Indian market

- Most of the manufacturers are selling product in the range of 1 to 2 ton capacity for both split and window type AC's.
- In the split type category, AC's with EER value of 3.85 are available in the market, which potentially lie in plus one efficiency level from current 5 star level of 3.5 EER. Several models of EER 3.63 and 3.66 models are available in the market. In case of window AC as well; manufacturers have achieved plus one level of efficiency from current 5 star level.

b) Techno-economic analysis

Component wise analysis

- Combination of individual components in an outdoor unit with CTAF heat exchanger costs around INR 7700 for base case and INR 12000 for the best available technology.
- Combination of individual components in an outdoor unit with CTAF-BAM heat exchanger costs around INR 7700 for base case and INR 9850 for the best available technology. The lesser heat exchanger area requirement to achieve higher efficiencies in the case of BAM constitutes the reason for the cost difference in the two cases.
- The incremental cost in individual components in moving from one efficiency level to next higher efficiency level is marginal and efficiency improvements are possible by the design modification and use of better technology.

Engineering Analysis

- EER improvement by 20% to 3.5(W/W) will require a retail price increase of Rs. 3060 (~10% increase over baseline) to cover the cost of efficiency improvement.
- EER of a Room AC improvement by over 30% to 4(W/W) will require a retail price increase of Rs. 10008 (~30% increase over baseline) to cover the cost of efficiency improvement.
- Increasing the stringency of MEPS is one of the key strategies to ensure improvement in the efficiency of the AC models sold in the market and should be evaluated rigorously considering the findings of this report.

Conclusions

- The key findings from market assessment and international comparison suggests that the market is prepared to move beyond the existing energy standards (MEPS) EER of 2.7 as of 2015 or 2.9 valid from 2016)
- The incremental cost analysis suggests that technologies/options are available and cost effective to move towards higher stringency without an appreciable cost increase to the consumer.
- Standard & labeling program for a variable (inverter) ACs (launched in October 2015) and a plan in place for a common rating table for fixed speed and variable speed ACs, the following requirements will need to be put in place:
    - move from EER to Cooling Seasonal Performance Factor (CSPF) rating plan
    - Outreach to make consumers aware for CSPF in place of EER
- From the Engineering analysis, following a least cost strategy, significant efficiency improvement can be achieved at a modest incremental manufacturing cost resulting in a marginal increase in retail price. The increase in price can be recovered relatively quickly through electricity bill savings.=

Annexure-1

1. Split AC Models – Singapore

The detailed specifications of the SAC models recorded and the analysis is now presented.

Table 433: Specifications of split air conditioners

Singapore		
Brand	**Model**	**Full load COP**
Daikin	RN25JV1G	3.6
Daikin	RN50JV1G	3.56
Daikin	RN60JV1G	3.52
Daikin	RN35JV1G	3.54
Daikin	R35GV1G	3.39
Daikin	R50GV1G	3.39
Daikin	R100LUV1	2.78
Daikin	RN25HV1G	3.38
Daikin	RN35HV1G	3.44
Daikin	RN50HV1G	3.39
LG	HSUC096B4A9	3.36
LG	HSUC126B4A5	3.34
Mitsubishi Electric	MU-D36VC	2.99
Mitsubishi Heavy Industries	SRC10CLV-7	3.59
Mitsubishi Heavy Industries	SRC13CLV-7	3.53
Mitsubishi Heavy Industries	SRC10CJV-4	3.35
York	YMFFYC036BBMSB-X	2.92
York	YMKFYC036BBMSB-X	2.92
York	YMFFYC024BBMSA-X	3.37
York	YMKFYC018BBMSA-1	3.35
York	YMKFYC024BBMSA-1	3.37
York	YMFFYC018BBMSA-1	3.36
York	YMHFYC009BBMVA-X	3.5
York	YMHFYC012BBMVA-X	3.51
York	YMHFYC018BBMVA-X	3.56
York	YMHFYC024BBMVA-X	3.42

2. Window AC Models

The detailed specifications of the WAC models extracted for Singapore, Australia-New Zealand and USA are provided below:

Table 444: Specifications of window air conditioners

Singapore				Australia- New Zealand				
Brand	**Model**	**Cooling Capacity (kW)**	**Full Load COP**	**Brand**	**Model**	**Output (kW)**	**Power Input (kW)**	**EER (W/W)**
Europ Ace	EWAC 309	2.78	3.14	TECO	TWW40C FBGJBB	4.09	1.22	3.35
FUJITECH	FW-09F	2.78	3.14	Kelvinator	KWH53H RC	5.3	1.62	3.27
FUJITECH	FW-12F	3.26	2.98	TECO	TWW53CF BGJBB	5.32	1.62	3.28
LG	UWC096CB AB1	2.72	3.09	Kelvinator	KWH53C RE	5.3	1.6	3.31
LG	UWC126CB AB1	3.45	2.98	GREE	GJC18AC-K6RN***	5.3	1.6	3.31
LG	UWC186NB AB1	4.79	3.07					
Midea	MWF-09CRN1-QC1G	2.79	3.13					
Midea	MWF1-12CRN1-QC1G	3.25	2.98					
Midea	MWF-16CRN1-QC1G	4.35	3.03					
York	YHUEC07C 5R-III	2.14	3.27					
York	YHUEC09C 5R-III	2.67	2.99					
York	YHUEC12C 5R-III	3.26	3.03					
York	YHUEC18C 5R-III	4.95	3.15					

United States of America (USA)			
Brand Name	**Model Number**	**Cooling Capacity (kW)**	**EER (w/w)**
Frigidaire	FFRE05W3Q1	1.46	3.26
Frigidaire	FFRE06C3Q1	1.75	3.26
Frigidaire	FFRE06W3Q1	1.75	3.26
Frigidaire	FFRE08C3Q1	2.33	3.29
Frigidaire	FFRE08W3Q1	2.33	3.29

Frigidaire	FFRE10C3Q1	2.92	3.29
Frigidaire	FFRE10W3Q1	2.92	3.29
Frigidaire	FFRE12C3Q1	3.50	3.29
Frigidaire	FFRE12W3Q1	3.50	3.29
Arctic King	AKSO+06CR4	1.75	3.26
Arctic King	AKSO+08CR4	2.33	3.29
Arctic King	AKSO+10CR4	2.92	3.29
Arctic King	AKSO+12CR4	3.50	3.29
Arctic King	AKW+05CR4	1.46	3.26
Arctic King	AKW+06CR4	1.75	3.26
Arctic King	AKW+08CR4	2.33	3.29
Arctic King	AKW+10CR4	2.92	3.29
Arctic King	AKW+12CR4	3.50	3.29
Arctic King	AKW+15CR4	4.38	3.26
Arctic King	AKW+18CR4-2	5.25	3.26
Arctic King	AKW+25CR4-2	7.29	2.85
Arctic King	MWK-06CRN1-BK2-v1	1.75	3.26
BestHome	MWK-10CRN1-BK3	2.92	3.29
BestHome	MWK-12CRN1-BK3	3.50	3.29
Continental Electric	CE11155ES	4.38	3.26
Daewoo	DWC-0520FCLE	1.46	3.26
Daewoo	DWC-0520FRLE	1.46	3.26
Daewoo	DWC-0560FCL	1.46	3.26
Daewoo	DWC-0560FRLE	1.46	3.26
Daewoo	DWC-0580FRLE	1.46	3.26
Daewoo	DWC-0620FCLE	1.75	3.26
Daewoo	DWC-0620FRLE	1.75	3.26
Daewoo	DWC-0660FCL	1.75	3.26
Daewoo	DWC-0660FRLE	1.75	3.26
Daewoo	DWC-0680FRLE	1.75	3.26
Daewoo	DWC-0820FCLE	2.33	3.29
Daewoo	DWC-0820FRLE	2.33	3.29
Daewoo	DWC-0860FCL	2.33	3.29
Daewoo	DWC-0860FRLE	2.33	3.29
Daewoo	DWC-0880FRLE	2.33	3.29
Daewoo	DWC-1020FCLE	2.92	3.29
Daewoo	DWC-1020FRLE	2.92	3.29
Daewoo	DWC-1060FCL	2.92	3.29
Daewoo	DWC-1060FRLE	2.92	3.29
Daewoo	DWC-1080FRLE	2.92	3.29
Haier	ESA405N	1.52	3.26

Haier	ESA405P	1.49	3.26
Haier	ESA406N	1.75	3.26
Haier	ESA408N	2.33	3.29
Haier	ESA410N	2.92	3.29
Haier	ESA412N	3.50	3.29
Haier	ESA415N	4.38	3.26
Haier	ESA418N	5.25	3.26
Haier	ESA424N	7.00	2.85
Keystone	KSTAW05B	1.46	3.26
Keystone	KSTAW06B	1.75	3.26
Keystone	KSTAW08B	2.33	3.29
Keystone	KSTAW10B	2.92	3.29
Keystone	KSTAW12B	3.50	3.29
KUL	KU31087ES	2.33	3.29
KUL	KU31107ES	2.92	3.29
KUL	KU31127ES	3.50	3.29
LIFESMART	LS-WAC12R	3.50	3.29
LIFESMART	LS-WAC6R	1.75	3.26
LIFESMART	LS-WAC8R	2.33	3.29
Ocean Breeze	OBZ-06ES	1.75	3.26
Ocean Breeze	OBZ-08ES	2.33	3.29
Perfect aire	2PAC12002	3.50	3.29
Polar Air	CYW-18C1A-G09AC	1.75	3.26
Polar Air	CYW-23C1A-S09AC	2.33	3.29
Polar Air	CYW-41C1A-L09AC	4.23	3.26
Polar Wind	MWK-06CRN1-BK2	1.75	3.26
Polar Wind	MWK-08CRN1-BK3	2.33	3.29
Polar Wind	MWK-12CRN1-BK3	3.50	3.29
Soleus Air	HCC-W12ES-A1	3.50	3.29
Soleus Air	HCC-W15ES-A1	4.23	3.26
Westpointe	MWK-06CRN1-BK2-v2	1.75	3.26
Westpointe	MWK-08CRN1-BK3	2.33	3.29
Westpointe	MWK-10CRN1-BK3	2.92	3.29
Westpointe	MWK-12CRN1-BK3	3.50	3.29
Westpointe	MWK-15CRN1-BK2	4.38	3.26
Westpointe	MWK-18CRN1-MK2	5.40	3.26
Westpointe	MWK-25CRN1-MI8	7.29	2.85
Westpointe	MWL-08CRN1-BJ9	2.33	3.17
Galanz	AW-08C61RK1(2)	2.33	3.29
Garrison	1028307	7.29	2.85
GE	AEH08LS**	2.36	3.32

GE	AEM05LS**	1.59	3.32
GE	AEM06LS**	1.76	3.26
GE	AEM06LT**	1.76	3.26
GE	AEM06LTQ1	1.76	3.26
GE	AEM10AS**	2.93	3.29
GE	AEM12AS**	3.50	3.29
GE	AEM14AS**	4.16	3.26
GE	AEM14AT**	4.21	3.26
GE	AEM18DS**	5.32	3.26
GE	AEM24DS**	7.06	2.85
GE	AEM24DT**	7.06	2.85
GE	AEM24DTH1	7.06	2.85
GE	AEN08LS**	2.36	3.29
GE	AEN10AS**	2.93	3.29
GE	AEN12AS**	3.44	3.29
GE	AEW05LT**	1.52	3.32
GE	AEW08LT**	2.35	3.29
GE	AEW08LTQ1	2.35	3.29
GE	AEW10AT**	2.95	3.29
GE	AEW12AT**	3.53	3.29
GE	AEW18DT**	5.25	3.26
GE	AHH10AS**	2.95	3.29
GE	AHH12AS**	3.50	3.29
GE	AHH18DTQ1	5.31	3.26
GE	AHH24DS**	7.00	2.85
GE	AHH24DS**	6.94	2.85

Annexure-2

1. Snapshot- Design and Construction process of heat exchangers

PwC team visited facility of few of leading OEMs in order to understand the design and construction process of the heat exchangers. The purpose was to understand the process and sensitivity for both CTAF and BAM. Both the facilities were equipped with advance technology and are proficient enough to provide good quality heat exchangers. The observations with respect to manufacturing of both CTAF and BAM are presented below:

- **CTAF Manufacturing Process:** The major raw material for CTAF manufacturing is the Copper tube and Aluminum metal sheet. The Copper tubes are mainly imported from China or Thailand. The Aluminum sheet is domestically available and can be imported from foreign countries. As part of the manufacturing process Aluminum sheet is shredded into small percolated films to make fins and which then set into the Copper tubes. Once the Copper tubes and aluminum fins are joined, the set is compressed into one unit in a compressing machine. This is the overall manufacturing process of Cooper Tube Aluminum Fin (CTAF) heat exchanger. The step wise manufacturing process of CTAF is highlighted at ***Figure 28.***

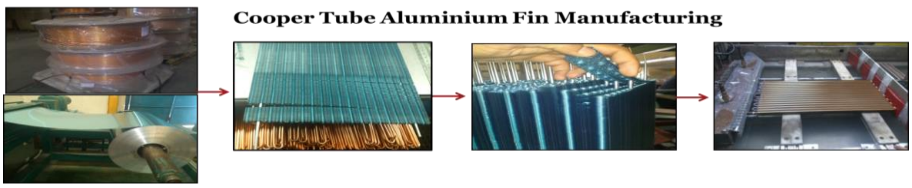


Figure 29 : CTAF manufacturing

- **BAM Manufacturing Process:** The raw material used in BAM manufacturing is the porous Aluminum strip. These strips are imported from Korea or China. Usually these are 16 or 8 pores strip depending upon the efficiency required from the heat exchanger system. The Aluminum strips are cut into desired length and then pre-fabricated Aluminum fins are set between the strips with the support of two perforated headers for refrigerant movement. After the unit is set into heat exchanger, it is heated in the furnace and cooled to get desired product.

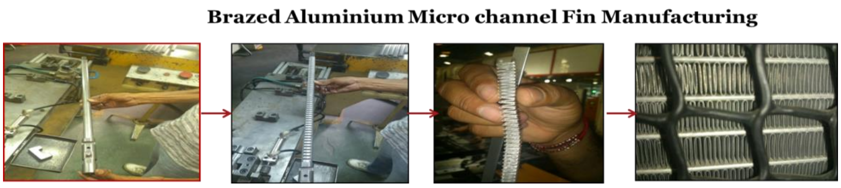


Figure 30 : BAM manufacturing

2. *Industrial Nomenclature for Condenser Heat Exchangers*

Nomenclature for CTAF condensers

Condenser heat exchangers have a well-defined industrial nomenclature which is followed industry wide. The nomenclature for split and window heat exchangers is presented **Table 45**.

Table 465: Nomenclature for CTAF

S No.	Air Conditioner	Definition
1	Split: 742C/24*2/18FPI/G	
2	Window: 570C/20*3/18FPI/G	

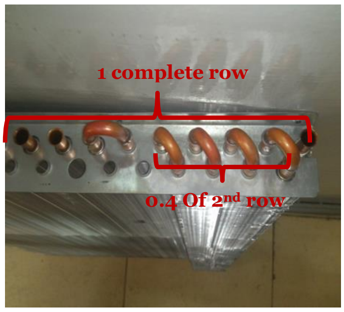
The condenser heat exchangers are sold based on the aforementioned nomenclature. Following pictorial representation will help to know the industrial nomenclature better. It is important to understand the nomenclature because this is used to understand heat exchanger design specifications.

- **Length of the Coil**: The length of the coil is the total vertical height of the heat exchanger. The standard length used by many manufacturers is 742 mm for the split air conditioner and 570 mm for window air conditioner.

- **Number of Coils**: The number of coils is the tubes in one row. In split air conditioners, the standard number of tubes in one row is 24. Manufacturer opts for number of tubes between 1 and 2 passes.

Length of Coil

- **Number of rows/passes**: The number of rows/passes help manufacturer to increase heat exchanger area within same outer dimensions. The picture provided below present a heat exchanger having 1.4 rows i.e. one complete row of 24 tubes and 0.4 percent coverage of second row.



- **Fins per Inch**: Fins are used to increase the surface area and U value for better heat transfer from the air conditioner within the given available space. It has been observed that manufacturers normally plat with Fins per square inch value between 16 to 22. The standard FPI used by manufacturers is 16. They go for higher values to increase surface area as per their design requirements.

  Discussions with manufacturers suggest that they mainly play with area of heat exchanger and fin design for efficiency improvement in comparison to altering U values.

- **Grooves**: Grooves are made inside the Copper tube in order to increase the heat transfer. Manufacturer mainly uses 7 mm tubes for heat exchangers. They move to 9 mm size as per the design requirement.

Fins per Inch