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Updated Market Assessment for Chillers in India

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Abbreviations

AHRI	Air Conditioning, Heating, & Refrigeration Institute
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
CAGR	Compound annual growth rate
COP	Coefficient of Performance
EC	Energy Conservation
EER	Energy Efficiency Ratio
FY	Financial Year
HVAC	Heating Ventilation and Air Conditioning
ICAP	India Cooling Action Plan
IS	Indian Standard
ISEER	Indian Seasonal Energy Efficiency Ratio
kW	Kilo Watts
NABL	National Accreditation Board for Testing and Calibration Laboratories
NDC	Nationally determined contribution
INDC	Intended Nationally determined contribution
RAMA	Refrigeration and Air Conditioning Manufacturer's Association
S&L	Standards and Labeling
TR	Tons of Refrigeration
YoY	Year on year

Executive Summary

The chiller in an HVAC system enables heat transfer from an internal air-conditioned space to the external environment, thus helping maintain the internal space at the desired temperature (which is lower than the external temperature). Cooling has become a necessity across multiple sectors such as automotives and transportion, industry, residential & commercial spaces, cold chain and refrigeration, etc. As the associated sectors continue to grow, the demand for cooling has increased and the market has grown at a CAGR of ~8.5% over the past five years.

The objective of this study is to facilitate the process of transition from the current voluntary program to a mandatory program for the S&L program for chillers. The voluntary S&L program for chillers was launched in September 2018. Currently, under the voluntary phase, 46 chiller models are registered across 6 major chiller manufacturers. To obtain inputs for the mandatory S&L phase, it is essential to assess the current market conditions. This study makes an effort to collate all the comprehensive data collected from primary and secondary sources, and draw recommendations for the mandatory phase of chiller S&L program.

The India Cooling Action Plan (ICAP) recommends retrofitting, and recommissioning of existing buildings as a measure to reduce energy consumption. According to ICAP, the energy consumption by chiller systems alone will account for 11% of space cooling energy consumption by the year 2037-38. The installed capacity of chillers in India is expected to reach 38.1 million Tons of Refrigeration (TR) by 2037-38, growing from the present 5.7 million TR as of 2021.

The market for cooling technologies is set to grow rapidly to keep up with India s cooling demands. The Bureau of Energy Efficiency's (BEE) Chiller S&L program can ride on this growth momentum to accelerate market penetration of energy efficient chillers. The growing chiller market also gives India an opportunity for energy savings, resulting in low carbon footprint by weeding out inefficient chillers through mandating the S&L program.

BEE, together with the CLASP, is therefore interested in mandating its existing voluntary S&L program. To achieve this, BEE and CLASP coordinated with Environmental Design Solutions to build a comprehensive assessment of the Indian chiller market. Data was collected through primary and secondary research to understand the current market as well as performance levels. This research focused on multiple aspects of the chiller market, such as overall market size, market segmentation across various types of chillers, and performance data of the different types and capacities each player makes.

The outcome of the study resulted in the following:

1. It was possible to understand performance distribution of chillers presently available in the market, and the overall improvement in performance level compared to the levels in the year 2020.
2. For the study, technical committee meetings were held with stakeholders, including manufacturers, manufacturers' associations, NABL BIS, and test labs. These meetings enabled players in the market to present the challenges faced by them to the BEE and the committee.
3. During the stakeholder discussions, **BEE and technical committee members jointly decided to transition the program to a mandatory labeling regime from 1st January 2023.**
4. The potential national impact in terms of energy savings and GHG reduction through the chiller S&L program has also been estimated. The cumulative energy savings from chiller S&L till 2030 is estimated to be **19.3 TWh** and **15.9 million-ton CO_2e.** Refer section 5 of the report for detailed analysis.

1. Introduction to Energy Efficiency Labeling of Appliances

Proliferating energy efficiency through S&L is cost-effective, as energy savings from such initiatives are generally assured, comparatively simple to quantify, and readily verifiable. S&L is thus a critical cornerstone for India's energy efficiency initiatives.

India has embarked upon an ambitious program to reduce the emissions intensity of its GDP by 33 to 35 percent by the year 2030, compared to its 2005 level, so as to meet its Nationally Determined Contribution (NDC)[1]. The conducive policy and regulatory regime created by the Ministry of Power, through the Bureau of Energy Efficiency (BEE) mentioned in the INDC document, is one of the measures taken towards achieving these targets. BEE aims to develop regulations and schemes with an impetus on self-regulation and market transformation, within the boundaries of the Energy Conservation Act (EC Act), 2001.

The prime objective of the bureau is to reduce the energy intensity of the Indian economy. This goal can be achieved only with the active participation of all stakeholders, facilitating faster adoption of energy efficiency in all sectors.

Energy use by appliances is expanding rapidly in India as more and more people acquire products such as refrigerators, Heating, Ventilation and Air Conditioning (HVAC) appliances, and consumer electronics. S&L is one of the various schemes and initiatives rolled out by BEE focusing on conserving energy.

1.1. S&L OF SPACE COOLING APPLIANCES

In ICAP and other reports[2,3] it is mentioned that cooling is associated with economic growth. Typical urban residential spaces occupied by upwardly socioeconomically mobile people with higher disposable income adopt active space cooling. Furthermore, the health, wellbeing, and productivity of people living in hot climates can often be dependent on cooling. Similarly, Shaikh et al state that humans spend ~90% of their time indoors, with indoor thermal comfort having a strong influence on the inhabitants' health, morale, working efficiency, productivity, and satisfaction[4].

Cooling has become a necessity across all sectors such as automotives and transport, industry, residential & commercial spaces, and cold chain and refrigeration, etc. With increasing GDP per capita and urbanization, cooling demand is expected to grow steadily in the future.

For space cooling solutions, BEE has launched programs that cover various categories and capacities of cooling appliances. Table 1 lists all the existing S&L programs for cooling appliances.

[1] Source: https://economictimes.indiatimes.com/news/india/india-set-to-update-its-2030-climate-targets-under-paris-agreement/articleshow/87098192.cms

[2] Ozone Cell, Ministry of Environment, Forest and Climate Change, GoI, "India Cooling Action Plan," March 2019. [Online]. Available: http://ozonecell.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdfhttp://ozonecell.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf.

[3] Sustainable and Smart Space Cooling Coalition (2017) , "Thermal Comfort for All - Sustainable and Smart Space," Alliance for an Energy Efficient Economy, New Delhi, 2017.

[4] P. H. Shaikh, N. B. M. Nor, P. Nallagownden, IrraivanElamvazuthi and T. Ibrahim, "A review on optimized control systems for building energy and comfort management of smart sustainable buildings," Renewable and Sustainable Energy Reviews, no. 34, pp. 409-429, 2014

TABLE 1 EXISTING ENERGY EFFICIENCY STANDARDS FOR SPACE COOLING APPLIANCES

Product	Scope	Applicable IS	Performance parameter
Room Air Conditioners (fixed speed)	Applicable to single-phase split, unitary air conditioners of vapor compression type for household use up to rated cooling capacity of 10.5 kW	IS 1391 part 1 and part 2	ISEER
Inverter air conditioners	Schedule applies to: • Air Conditioners working on single-phase power up to & including 250V alternating current. • Variable capacity split & unitary air conditioners, commercially known as Inverter air conditioners, of vapor compression type for household & similar use up to and including a rated cooling capacity of 10.5 kW	• IS 1391 part 1 and part 2 with all amendments. • Based on 1600 bin hours • ISO 16358-1: 2013 (E) for calculating ISEER/CSPF	ISEER
Chillers	Covers all types and sizes/capacity for rated voltage up to & including 250 V, 50 Hz AC, for single-phase, and up to & including 11kV, 50Hz AC for three-phase power supply	IS 16590: 2017	ISEER
Light commercial air conditioners (LCAC)	Single and three-phase non-ducted single split with fixed and variable speed air-conditioner with a rated capacity above 10.5 kW up to & including 18.0 kW of vapor compression type covered	IS 1391 (Part 2): 2018	ISEER

1.2. CHILLERS

A chiller in an HVAC system enables heat transfer from an internal conditioned space to the external environment, thus helping maintain the internal space at a desired temperature lower than the external temperature. The functioning of the chiller depends on the physical state of the refrigerant that circulates in the chiller circuit. The chiller is termed as the heart of the central HVAC system as it continually cools the coolant (e.g., water) at the desired temperature. Subsequently, the coolant is pumped through the Air Handling Units (AHU) in the case of space cooling, and through the processes like metal cutting, machining, deep freezing, etc., in the case of machinery and process equipment cooling. The coolant extracts the heat out of the conditioned spaces and the controlled processes before returning to the evaporator side of the chiller.

Chillers work on either vapor compression technology or vapor absorption technology. This market study is confined to chillers working on the vapor compression refrigeration system.

A chiller working on vapor compression technology comprises four major components viz., evaporator, compressor, condenser, and expansion valve. A schematic of a water-cooled chiller is shown in Figure **1**. In a chiller, the refrigerant circulates through all these components and different thermodynamic processes occur within each of these components.

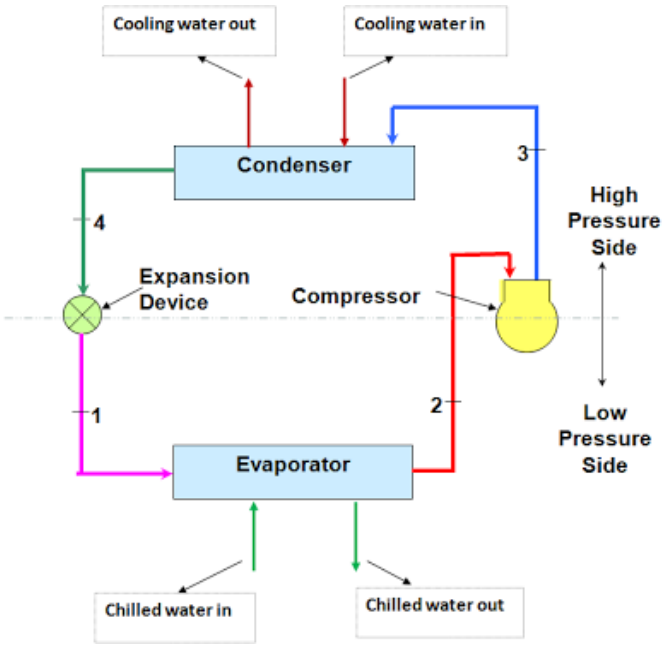

FIGURE 1 SCHEMATIC OF A WATER-COOLED CHILLER

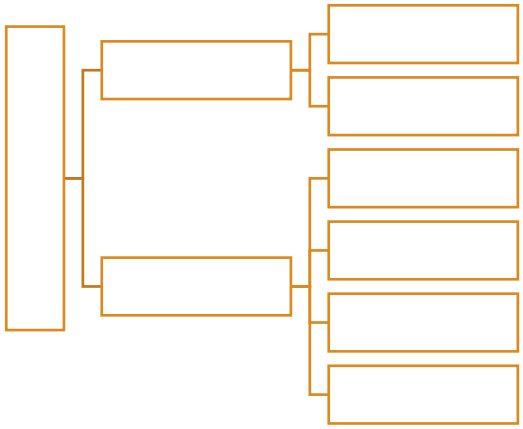

FIGURE 2 CLASSIFICATION OF CHILLERS

On the evaporator side of the chiller, the evaporator acts as a heat exchanger, where the low-pressure refrigerant liquid extracts energy (heat) from the coolant which has cooled a space or process. Due to this heat transfer between the low-pressure, low-temperature liquid refrigerant and the coolant (water), the refrigerant turns into low-pressure vapor, reducing the temperature of the coolant. From the evaporator, the refrigerant flows to the compressor.

The compressor primarily helps to maintain low pressure in the evaporator and aids good heat transfer there. Additionally, it raises the pressure of outgoing refrigerant vapor. This high-pressure, high-temperature refrigerant vapor from the compressor rejects the energy (heat) in the condenser and changes to a low-temperature refrigerant liquid. The energy given out by the refrigerant in the condenser is carried away by a condenser cooling medium, which is either water or air[5]. Then, the low-temperature, high-pressure liquid refrigerant from the condenser passes through the expansion valve and changes to low temperature and low-pressure liquid refrigerant and the cycle continues.

Chillers can be classified depending on type of condenser cooling media or type of compressor technology. The classification of chillers is depicted in Figure **2**. In the case of water-cooled chillers, the condenser is connected with a cooling tower.

[5] Information: Water-cooled systems are more efficient for heat transfer than air-cooled systems because air-cooled systems are limited by the dry bulb temperature, resulting in higher condensing temperatures and therefore lower chiller efficiency. However, since water-cooled systems require cooling towers and associated water pumps, piping, fans, and water treatment systems, they have higher installation and maintenance costs than air-cooled alternatives. Source: Management of Heating and Cooling, Craig B. Smith, Kelly E. Parmenter, in Energy Management Principles (Second Edition), 2016.

FIGURE 3 TYPICAL WATER-COOLED CHILLER

FIGURE 4TYPICAL AIR-COOLED CHILLER

2. Standards and Labeling (S&L) of Chillers

The voluntary phase S&L program for chillers was launched by the BEE in September 2018. As participation in the program is voluntary, the adoption of S&L for chillers is in a nascent stage[6]. The penetration of BEE certified high-efficiency chillers in the market is not significant and needs to be driven further.

2.1. VOLUNTARY PHASE S&L REGIME[7]

BEE's extant labelling program specifies the energy efficiency labelling requirement for chillers working on a vapor compression cycle, and covers all types, and sizes or capacities of chillers rated at voltage up to & including 250 V, 50 Hz AC for single-phase power supply, and up to & including 11kV, 50Hz AC for three-phase power supply covered under the scope of IS 16590. Chillers are rated based on Indian Seasonal Energy Efficiency Ratio (ISEER), and must comply with prequalification criteria i.e., every model shall achieve a minimum COP to become eligible for a star rating plan. The prequalification criteria and the star rating levels for air-cooled and water-cooled chillers are presented in the following tables.

[6] As per the inputs received from some of the chiller manufacturers it is understood that the some of the major players are adopting BEE star rating.

[7] https://www.beestarlabel.com/Content/Files/Chillers_schedule_21.pdf

TABLE 2 PREQUALIFICATION CRITERIA FOR WATER-COOLED CHILLERS

kW of Cooling	Min. COP required (@100% load)
<260	4.2
>=260 & <530	4.7
>= 530 & <1050.	5
>= 1050 & <1580	5.2
>=1580	5.6

TABLE 3 PRE-QUALIFICATION CRITERIA FOR AIR-COOLED CHILLERS

kW of Cooling	Min. COP required (@100% load)
<260	2.4
>=260	2.6

TABLE 4 STAR RATING LEVELS (ISEER VALUES) FOR WATER-COOLED CHILLERS (TABLE VALIDITY PERIOD 1ST JANUARY 2019 TO 31ST DECEMBER 2021)

kW of cooling	1 Star	2 Star	3 Star	4 Star	5 Star
<260	4.8	5.2	5.6	6.1	6.6
>=260 & <530	5	5.6	6.2	6.8	7.4
>= 530 & <1050	5.5	6.1	6.7	7.4	8.2
>= 1050 & <1580	5.8	6.5	7.2	7.9	8.7
>=1580	6	6.7	7.4	8.2	9

TABLE 5 STAR RATING LEVELS (ISEER VALUES) FOR AIR-COOLED CHILLERS (TABLE VALIDITY PERIOD 1ST JANUARY 2019 TO 31ST DECEMBER 2021)

kW of cooling	1 Star	2 Star	3 Star	4 Star	5 Star
<260	3	3.3	3.6	4	4.4
>=260	3.1	3.5	3.9	4.3	4.7

In the chiller S&L program, IS16590:2017 is the reference standard. The standard describes the chiller testing methodology, rating conditions, and associated calculations for determining the ISEER, and covers full-load and part-load rating test methods.

2.2. PARTICIPATION IN VOLUNTARY PHASE S&L

The current S&L program for chillers is in the voluntary phase, and has been adopted by prominent chiller manufacturers in the industry. Presently, six (6) chiller manufacturers are participating in the voluntary phase S&L program[8]. The list of manufacturers registered in the program is given below.

As reported by BEE, registration requests have been received for a total of fifty-three (53) chiller models across six (6) manufacturers. However, out of these fifty-three (53), only forty-six (46) models have been accepted and registered. The remaining seven (7) are kept on hold[9]. Among the forty-six (46) registered models, thirty-two (32) are air-cooled and fourteen (14) are water-cooled models. Out of these forty-six (46) models, thirty (30) models are scroll chillers, fourteen (15) are screw chillers, and one (1) is a centrifugal chiller. The categorization of the registered chiller models is depicted in Figure 5. The cooling capacity of registered models ranges from 5.7kW to 1579.15kW. The highest ISEER (Indian Seasonal Energy Efficiency Ratio) reported in the voluntary S&L program is 8.15, for a 508kW (144TR) chiller with a screw compressor and water-cooled condenser.

[8] As reported in the BEE's portal; http://beestarlabel.com/SearchCompare

[9] Source: Information from BEE officials.

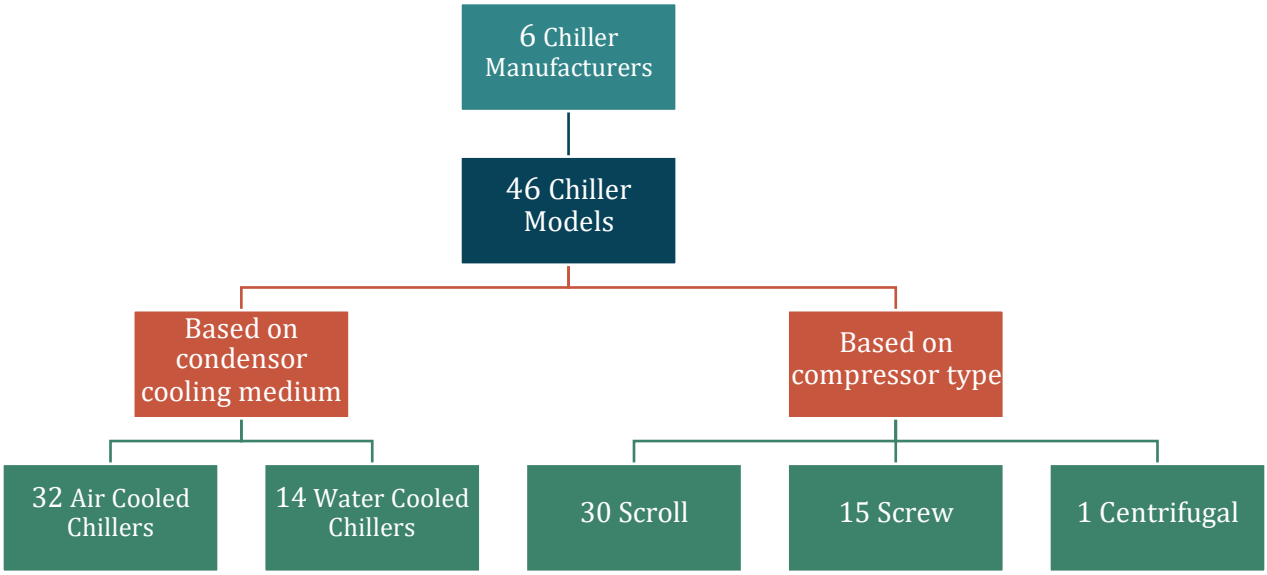

FIGURE 5 CATEGORISATION OF CHILLER MODELS

The forty-six (46) registered chiller models in the voluntary phase are spread across different star rating levels. The distribution of these chiller models across different star rating levels based on the cooling capacities is presented in the following tables.

TABLE 6 DISTRIBUTION OF REGISTERED WATER-COOLED MODELS CHILLERS IN VOLUNTARY PHASE S&L

kW of cooling	1 Star	2 Star	3 Star	4 Star	5 Star
<260	-	-	-	-	1 model
>=260 & <530	-	-	-	-	7 models
>= 530 & <1050	-	-	-	3 models	-
>= 1050 & <1580	-	-	-	3 models	-
>=1580	-	-	-	-	-

TABLE 7 DISTRIBUTION OF REGISTERED AIR-COOLED MODELS CHILLERS IN VOLUNTARY PHASE S&L

kW of cooling	1 Star	2 Star	3 Star	4 Star	5 Star
<260	-	1 model	13 models	3 models	1 model
>=260	-	5 models	8 models	-	1 model

2.3. NECESSITY FOR MANDATORY PHASE S&L OF CHILLERS

According to the India Cooling Action Plan (ICAP), chiller systems will account for 11% of space cooling energy consumption by the year 2037-38. The installed capacity of chillers in India is expected to reach 38.1 million Tons of Refrigeration (TR) by 2037-38, from the present 5.7 million TR.

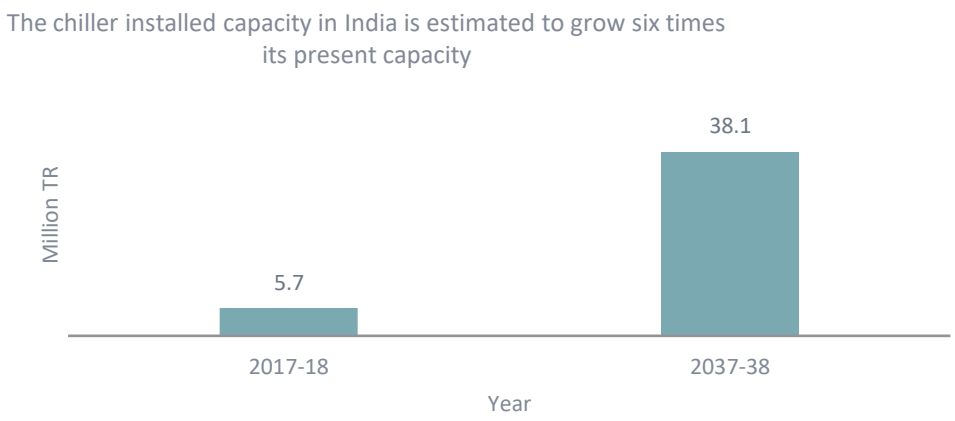

FIGURE 6 ESTIMATED GROWTH IN CHILLERS

As per RAMA[10] estimate, future growth in the chiller industry is driven by growth in retail, hospitality, and infrastructure projects. It is projected to grow at a CAGR of 9-10% for centrifugal, 3-5% for scroll, and 6-8% for screw chillers in the next 10 years[11]. Commercial and industrial spaces are the biggest consumers of chillers in India; approximately 1/6th of the yearly sales are for the replacement of older chillers[12]. The chiller market in India is not just limited to new installations, there is also a large scope in existing installations[13]. In existing buildings, chillers may be old and less efficient as compared to new ones in the market. As recommended in the ICAP, retrofitting and recommissioning of existing buildings is one of the measures needed to be taken in order to reduce energy consumption. Thus, the existing stock and the new demand adds up, making the market of chillers very large, while simultaneously giving the country an opportunity for energy savings that could result in a lower carbon footprint.

Presently, in the chiller market, both energy-efficient and quality chillers as well as the cost-competitive inefficient ones are available. Hence, as the chiller market grows, regulating the performance of chillers becomes necessary. However, the unorganized sector specializes in smaller capacity chillers, and mandating the energy-efficiency standards is an essential step towards regulating the energy consumption of these chillers. Accordingly, BEE with the support of CLASP, proposes to introduce a mandatory S&L program for chillers.

[10] Refrigeration and Air Conditioning Manufacturer's Association

[11] Source: India Action Cooling Plan. 2019

[12] IBID

[13] Service life of chillers considered is 15 years.

3. Market Assessment

Market assessment aids in understanding the following aspects.

a) Growth of the chiller market

b) Market and product segmentation

c) Current performance levels

Obtaining full understanding of the chiller market characteristics in India is fundamental in establishing a sound basis to support policy-making decisions. To collect all pertinent information required for high reliability in policy analysis efforts, the market assessment is done in two modes — primary research and secondary/desk research.

Primary research covered collection of relevant data in the form of questionnaire-based responses from the chiller industry stakeholders, who play a major role in any policy decision. Secondary research covered information such as market players, installed capacity of chillers in India, sales over previous years, growth trend, etc. The data collected from secondary methods have been validated through consultative discussions with experts[14] from the industry.

2.4. MARKET OPPORTUNITY

'India Cooling Action Plan' (ICAP), published in the year 2019[15], provides valuable insights into the complete HVAC ecosystem in the country. According to the action plan, growth in retail, hospitality, and infrastructure projects will increase the demand for chillers. Additionally, the centrifugal, scroll and screw chillers were projected to grow at a CAGR of 9-10%, 3-5%, and 6-8% respectively in the next 10 years.

Chillers are of two types — air-cooled chillers and water-cooled chillers. These chiller types are then broadly categorized into three types based on their compressor technology[16]; Table 8 list the types of chiller, their cooling capacity ranges, and their approximate market share. It is projected that the demand for scroll chillers will reduce and screw chillers will increase in the future, due to the higher efficiencies associated with screw chillers.

TABLE 8 TYPES OF CHILLERS AND THEIR ASSOCIATED MARKET SHARE

Type of chillers (based on compressor tech.)	Approximate cooling capacity range (TR)	Approximate market share
Scroll chiller	10 to 150	10%
Screw chillers	50 to 500	55%
Centrifugal chillers	300 to 2500	35%

From Table 8 it can be observed that screw chillers and centrifugal chillers account for the majority of market share. These large capacity chillers are usually employed in comfort cooling (space cooling) applications. Hence, the space

[14] representatives from chiller manufacturing companies

[15] Ministry of Environment, Forest & Climate Change (2019). India Cooling Action Plan. New Delhi: Ministry of Environment, Forest & Climate Change

[16] As reported by Refrigeration and Air Conditioning Manufacturer's Association (RAMA) in the ICAP

cooling segment provides a good opportunity to drive energy efficiency, and mandating S&L in chillers could result in energy and GHG savings.

2.2. MARKET PLAYERS

As part of the primary data, insights from leading stakeholders from the chiller industry were collected. The information was collected in the form of questionnaires and semi-structured interviews, and the list of players involved in the survey is listed in Figure 7.

Daikin India	Swegon (Blue Box)	Voltas	Danfoss	Bluestar	Climaveneta	Johnson Control--Hitachi Air Conditioner India ltd
Johnson Control India. Pvt ltd	Carrier	Dunham-bush	Trane	LG	Kirloskar	Emerson Climate Technologies (India) Ltd.

FIGURE 7 MANUFACTURERS INVOLVED IN MARKET ASSESSMENT

2.3. ORGANISED AND UNORGANIZED MANUFACTURERS[17]

As per market consensus, unorganized chiller manufacturers are those whose chillers are not regulated and are flexible to design changes. They produce customized chillers that are non-standard. On the contrary, a manufacturer from the organized sector will have their products certified and compliant with regulations defined by the national body. The performance numbers declared by organized manufacturers have the strong authenticity of third-party certification agencies. Unorganized players mostly do not have their own test labs, and their chillers are not tested by any third-party certified labs.

The majority of the unorganized players operate majorly in the <260kW capacity chiller market. Their presence in the higher capacity chiller market is comparatively less. In the <260kW capacity range, unorganized manufacturers account for 70% to 80% of revenue. Due to their flexibility and customization capabilities, unorganized players get business from process cooling applications. Manufacturing higher capacity chillers is a resource-intensive segment requiring skilled trained manpower, cranes, test labs simulation software etc., which is cost prohibitive and challenging for the unorganized sector. In the >260kW chiller segment, majority (~90%) of the sales serves space cooling requirement, and ~10% serves process cooling requirement.

2.4. CHILLER MARKET

The chiller manufacturers majorly cater to two segments: the process cooling segment and the space cooling segment. The numbers representing the market size will include both the process cooling as well as space cooling segment. The size of the chiller market can be represented in terms of ***'units per year'*** or ***'TR per year'***. A complete understanding of the size of the chiller market requires looking at both ***'units per year'*** as well as ***'TR per year'*** because ***'units per year'*** may not reveal the actual growth in cooling capacity (TR) requirement.

Figure 8 and Figure 9 shows the growth in the market over the last five years. The numbers presented in the graph (Figure 8 and Figure 9) include all types and capacities of chillers ranging from as low as 5 TR. Small capacity chillers are high in numbers, and they majorly meet the process cooling segment. Chillers with reciprocating compressors and scroll compressors are used in small capacity process cooling requirements. The chiller market in terms of ***units per year*** has grown at a ***rate of ~5.1%*** over the last five years. In terms of ***'TR per year'*** it has grown at a ***rate of 8.5%.***

[17] The information presented in the section is based on the interviews of chiller manufacturers.

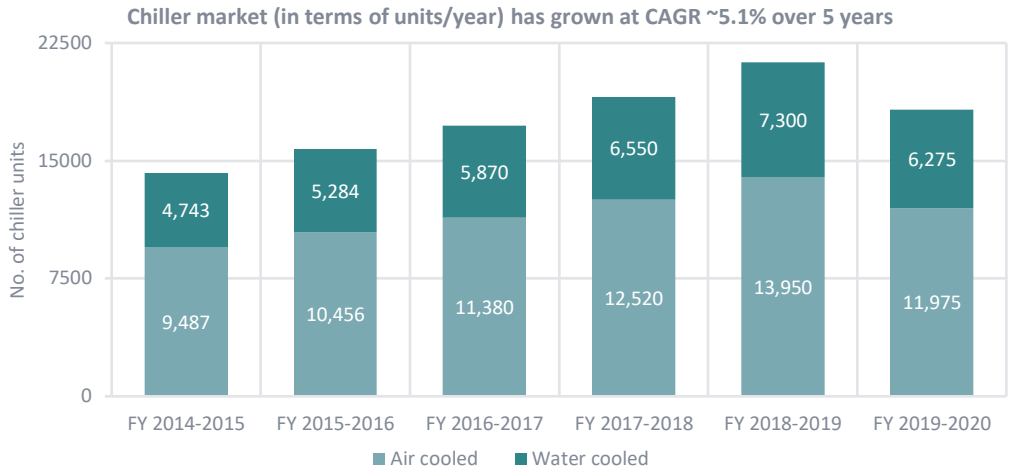

FIGURE 8 GROWTH OF CHILLER MARKET (IN TERMS OF NUMBER OF UNITS/YEAR)[18]

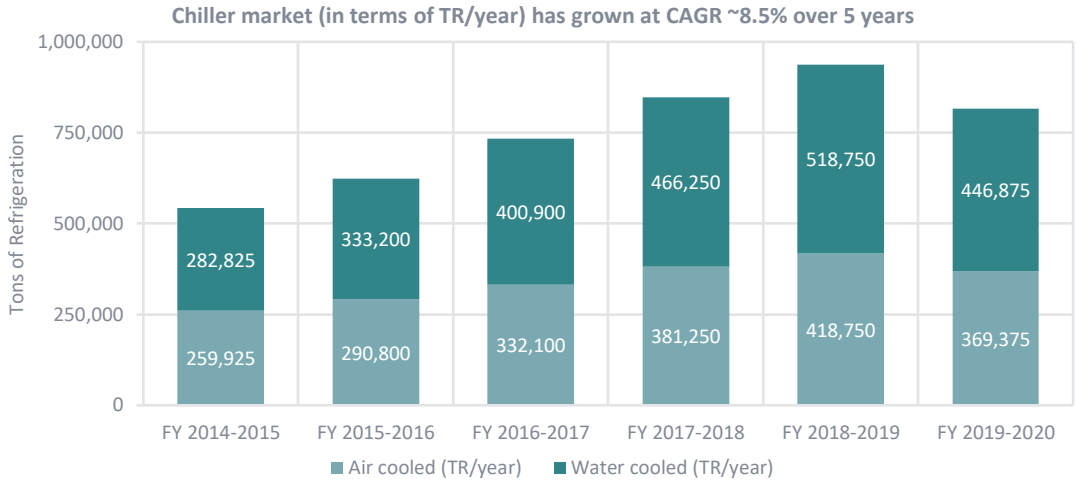

FIGURE 9 GROWTH IN CHILLER MARKET (IN TERMS OF TR/YEAR)

2.5. CHILLER MARKET SEGMENTATION

The chiller market is usually categorized into ***air-cooled chillers*** and ***water-cooled chillers.*** In terms of ***'TR per year'*** the air-cooled and water-cooled chiller market has grown at a CAGR of 7.3% and 9.6% respectively over the past five (5) years. However, in terms of '***units per year'***, the air-cooled and water-cooled chiller market has grown at a CAGR of 4.8% and 5.8% respectively over the past five (5) years.

The chiller market can be further segmented depending on the application as well viz.**,** ***process cooling*** and ***space cooling application***. In the process cooled water or brine is used as the heat transfer media. The required outlet temperatures are different according to applications. Chilled water temperature range is between 10℃ to 25℃, while chilled brine temperature ranges from (-)10℃ to (-)25℃. Plastics, shoe Industry, food & beverage etc. are some of the major industries that are consumers of process cooling chillers.

[18] Source: Based on the data received from chiller manufacturers in primary research

Figure 10 shows the share of space cooling and process cooling in terms of TR/year in the total chiller market. In terms of TR/year, the space cooling and process cooling segment has grown at a CAGR of 9.8% and 4.4% respectively.

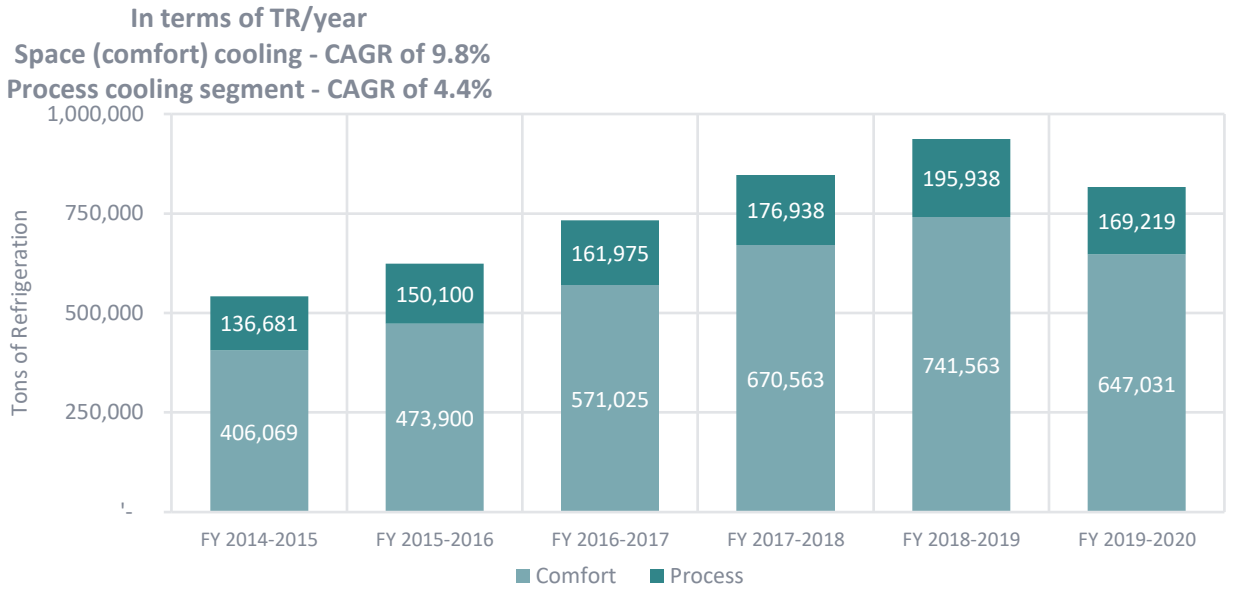

FIGURE 10 SHARE OF SPACE COOLING AND PROCESS COOLING IN TOTAL CHILLER MARKET

Figure 11 shows the share of space cooling and process cooling in terms of no. of units/year in the total chiller market. In terms of the units per year, the process cooling and space cooling segments has grown at a CAGR of 4.3% and 6.5% respectively.

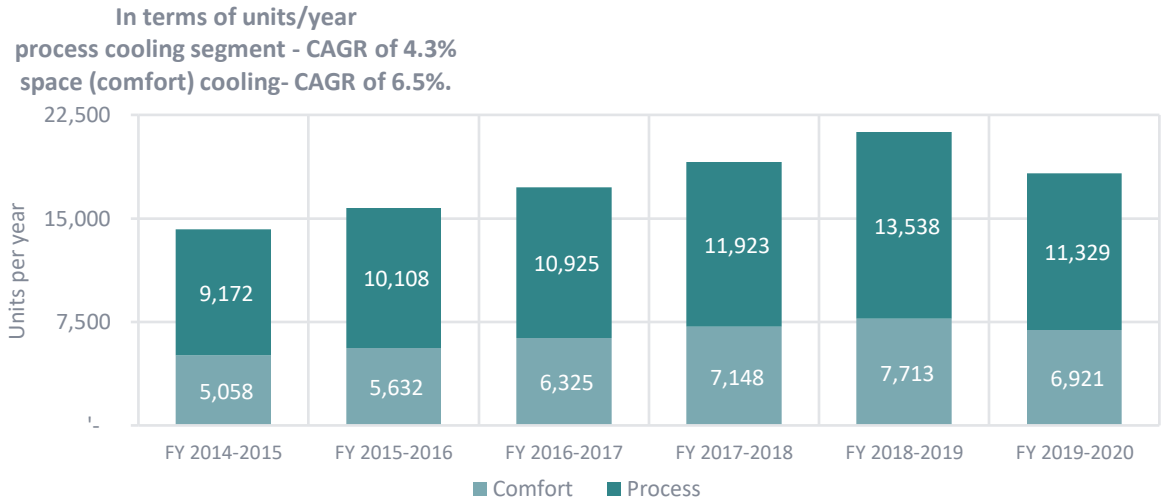

FIGURE 11 SHARE OF SPACE AND PROCESS COOLING IN TOTAL CHILLER MARKET

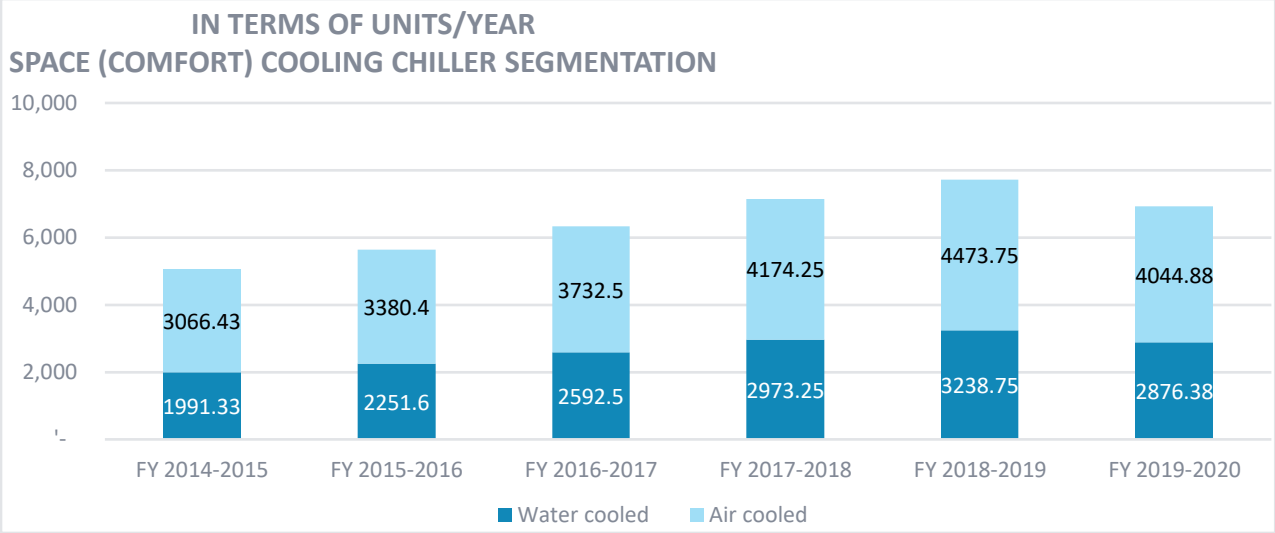

FIGURE 12 SEGMENTATION OF SPACE COOLING CHILLERS

The summary of chiller market segmentation and growth in every segment is presented in Table 9. The numbers presented in the table give insights into the chiller market. The growth in the chiller market is driven by the space cooling segment and water-cooled type chillers.

TABLE 9 BRIEF SUMMARY OF CHILLER MARKET SEGMENTATION AND GROWTH IN EACH SEGMENT

	In terms of no. of units/year		In terms of TR/year	
	CAGR over the past 5 years	Average market share	CAGR over the past 5 years	Average market share
Air cooled chillers (process & space cooling combined)	4.8%	66%	7.3%	46%
Water cooled chillers (process & space cooling combined)	5.8%	34%	9.6%	54%
Space cooling segment	6.5%	37%	9.8%	78%
Process cooling segment	4.3%	63%	4.4%	22%
Air cooled chillers (Space cooling)	7.6%	41%	10.3%	61%
Water cooled chillers (Space cooling)	5.7%	59%	8.8%	39%

2.6. MARKET FORECAST

Based on the data presented in the previous section, it observed that the chiller market has grown at a CAGR of 8.5% in terms of ***'TR per year'***. Table 9 presents the growth rate in each market segment. For forecasting the market growth, the financial year 2019-2020 is used as the base year and the respective growth rates for water cooled and air-cooled chillers are used to estimate future sales. Figure 13 presents the forecast of the chiller market in terms of ***'TR per year',*** depicting absolute cooling demand irrespective of the number of units sold.

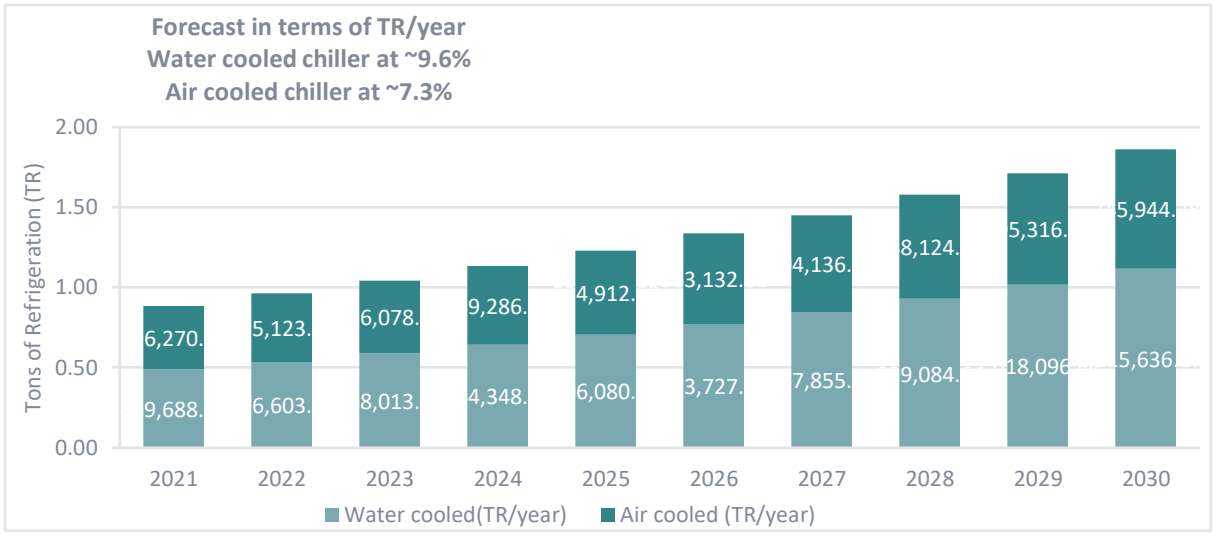

FIGURE 13 CHILLER MARKET FORECAST IN TERMS OF TR/YEAR

The forecast in terms of units per year is presented in the Figure 14.

Figure 14 also provides information regarding the estimated growth in individual segments like water cooled and air-cooled chillers.

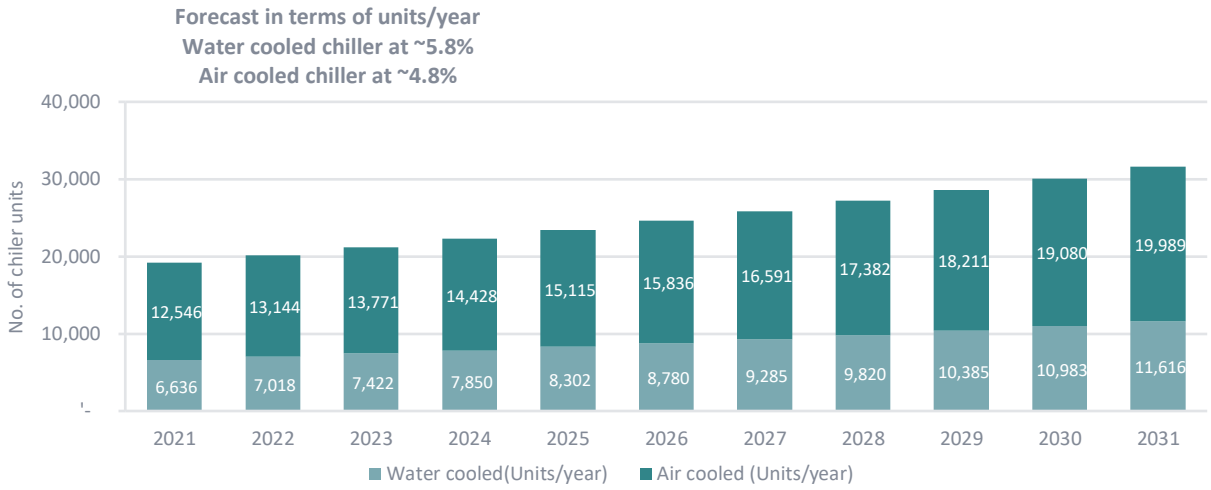

FIGURE 14 MARKET FORECAST IN TERMS OF UNITS/YEAR

2.7. CHILLER TESTING INFRASTRUCTURE

AS A CHILLER IS A COMPLEX HIGH VALUE COOLING EQUIPMENT, IT IS ESSENTIAL TO TEST ITS FUNCTIONALITY AND PERFORMANCE PRIOR TO SHIPPING TO THE SITE. THEREFORE, IT IS NECESSARY FOR ALL THE CHILLER MANUFACTURERS TO HAVE A TEST FACILITY AT THEIR MANUFACTURING LOCATION.

The S&L program [19] for chiller mandates requires accreditation of test facilities. To qualify for BEE's star labeling program, the chiller must be tested in an NABL accredited test facility. Currently, there are no independent or manufacturer-owned test labs that are NABL accredited and can test the chillers as per IS16590[20]. However, one manufacturer's lab is accredited by NABL to test chillers in India as per AHRI 550/590.

The Indian chiller market has both local and overseas manufacturers, and these players have testing facilities at their manufacturing location. In a questionnaire-based survey, some manufacturers shared information pertaining to their testing infrastructure.

The list of test facilities, along with preliminary information on the respective testing capacity for chillers, is shared below in Table 10

TABLE 10 CHILLER TESTING CAPACITY IN INDIA

Serial No.	Manufacturer	Is the chiller testing facility available in India or overseas? (yes/No)	Is the test facility NABL/ ILAC/ APAC accredited for testing chillers as per IS16590? (Yes/No)	Is the test facility AHRI or Eurovent certified? (Yes/No)	Testing capacity per month
1.	Climaveneta	Test facility Available in India	No	Yes	14
2.	Daikin	Test facility Available in India	Yes	Yes	60
3.	Voltas	Test facility Available in India	No	Yes	30
4.	Swegon	Test facility available in Italy	NA	NA	NA
5.	Danfoss	Test facility Available in India	No	No	5
6.	Bluestar	Test facility Available in India	No	Yes	5
7.	JCI Hitachi	Test facility Available in India	No	No	25

[19] https://www.beestarlabel.com/Home/EquipmentSchemes?type=V

[20] As per the information available on the NABL's website

Serial No.	Manufacturer	Is the chiller testing facility available in India or overseas? (yes/No)	Is the test facility NABL/ ILAC/ APAC accredited for testing chillers as per IS16590? (Yes/No)	Is the test facility AHRI or Eurovent certified? (Yes/No)	Testing capacity per month
8.	JCI	Test facility available in China	NA	NA	NA

4. Technical Assessment

In the market survey performance (ISEER values) data of two hundred and nineteen (219) chiller models was received. Out of two hundred and nineteen (219) models, one hundred and fifty two (152) models are water-cooled, and the remaining sixty seven (67) models are air-cooled. The performance data collected in the survey is compared with the current voluntary S&L program to understand the position of the current chiller market.

4.1. PERFORMANCE COMPARISON OF WATER-COOLED CHILLERS

This section presents the performance comparison of water-cooled chillers in the market with the performance thresholds set in voluntary S&L program. Table 11 presents the comparison of ISEER values of the current water-cooled chiller models in the market with the voluntary S&L program.

TABLE 11 COMPARISON OF CURRENT VOLUNTARY S&L PROGRAM WITH PERFORMANCE REPORTED IN THE SURVEY FOR WATER-COOLED CHILLERS

Current voluntary S&L rating levels (ISEER) for water-cooled chillers as mentioned in BEE schedule 21						Minimum and Maximum ISEER of water-cooled chillers as reported in the survey		
kW of cooling	1 Star	2 Star	3 Star	4 Star	5 Star	Minimum ISEER	Maximum ISEER	The number of models reported in the survey for the given cooling capacity range.
<260	4.8	5.2	5.6	6.1	6.6	4.9	6.8	6
>=260 & <530	5	5.6	6.2	6.8	7.4	5.0	8.7	32
>= 530 & <1050	5.5	6.1	6.7	7.4	8.2	5.4	8.8	58
>= 1050 & <1580	5.8	6.5	7.2	7.9	8.7	5.3	9.2	47
>=1580	6	6.7	7.4	8.2	9	6.2	8.5	9

From Table 11 it can be observed that except for the large capacity (>1580kW) chillers, the ISEER of current water-cooled chillers models in the market exceeds the 5-star S&L requirement. Table 12 presents the distribution of 152 water-cooled chiller models across different star rating levels. From the table, it can be observed that there are 7 chiller models which do not qualify to be star rated as these models fail to meet the pre-requisite criteria (COP) set in BEE's S&L schedule. Table 11 shows the range (min. and max.) of ISEER values that are reported in the survey. To get a clear picture of chiller performance distribution, the total number of chiller models in each star category is plotted in Figure 15.

TABLE 12 DISTRIBUTION OF CHILLER MODELS ACROSS DIFFERENT STAR RATING LEVELS FOR WATER-COOLED CHILLERS

kW of cooling	0 Star	1 Star	2 Star	3 Star	4 Star	5 Star	Total ↓
<260	0	1	1	1	0	3	**6**
>=260 & <530	0	4	7	7	4	10	**32**
>= 530 & <1050	3	23	8	10	5	9	**58**
>= 1050 & <1580	4	16	5	7	3	12	**47**
>=1580	0	1	3	2	3	0	**9**
Total →	**7**	**45**	**24**	**27**	**15**	**34**	**152**

From Figure 15 it can be observed that the majority of the water-cooled chiller models lie below the 4-star category. Therefore, there is a good opportunity in chiller manufacturing to improve the energy efficiency of current and upcoming models.

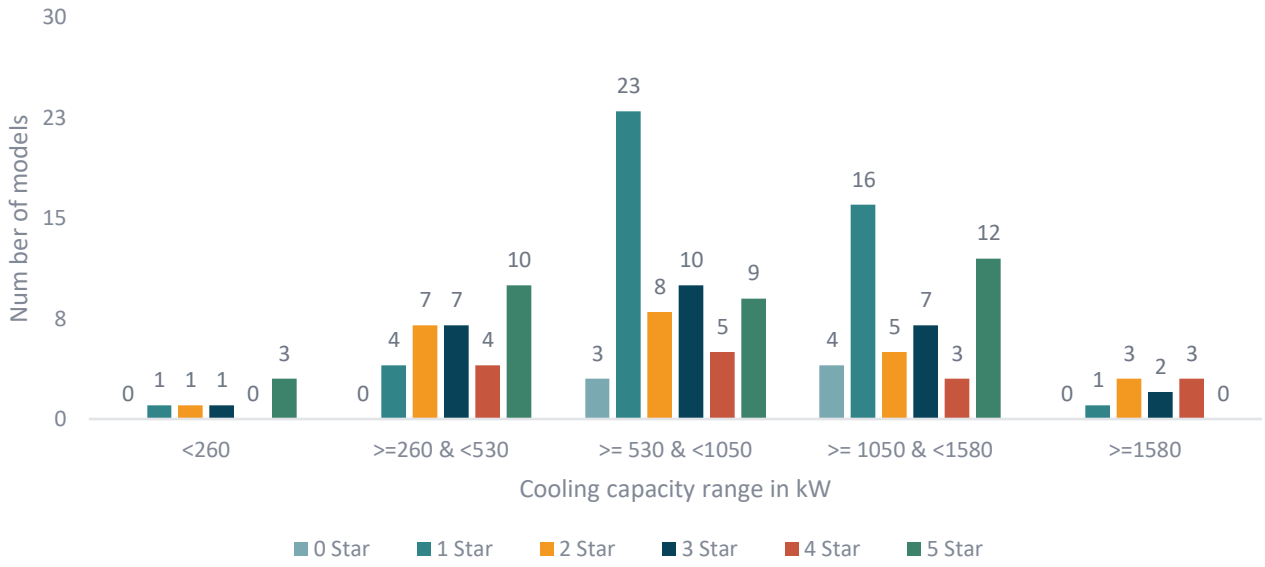

FIGURE 15 PERFORMANCE DISTRIBUTION OF WATER-COOLED CHILLERS IN THE CURRENT MARKET

4.2. PERFORMANCE COMPARISON OF AIR-COOLED CHILLERS

This section presents the performance comparison of air-cooled chillers in the market with the performance thresholds set in voluntary S&L program. Similarly, for air-cooled chillers Table 13 presents the comparison between the performance (ISEER) of currently available chillers in the market and the voluntary S&L program.

TABLE 13 COMPARISON OF CURRENT VOLUNTAYR S&L PROGRAM WITH PERFROMANCE REPORTED IN THE SURVEY FOR AIR COOLED CHILLERS

Current voluntary S&L rating levels (ISEER) for air cooled chillers as mentioned in BEE schedule 21						Minimum and Maximum ISEER of air-cooled chillers as reported in the survey		
kW of cooling	1 Star	2 Star	3 Star	4 Star	5 Star	Minimum ISEER	Maximum ISEER	Number of models reported in the survey for the given cooling capacity range.
<260	3	3.3	3.6	4	4.4	3.3	4.8	24
>=260	3.1	3.5	3.9	4.3	4.7	3.5	4.7	43

From Table 13 it can be observed that the performance of chillers available in the market has reached 5-star performance levels. Table 13 shows the range (min. and max.) of ISEER values of air-cooled chillers that are reported in the survey. However, it is necessary to understand performance distribution of chiller models across 1-star to 5-star ratings. For air-cooled chillers the performance distribution is given in Table 14, which presents the distribution of sixty-seven (67) air-cooled chiller models across different star rating levels. From the table, it can be observed that there are two (2) chiller models which do not qualify to be star rated, as they fail to meet the pre-requisite criteria (COP) set in BEE's S&L schedule. To get a clear picture of chiller performance distribution, the total number of chiller models in each star category is plotted in Figure 15.

TABLE 14 DISTRIBUTION OF CHILLER MODELS ACROSS DIFFERENT STAR RATING LEVELS FOR AIR-COOLED CHILLERS

kW of cooling	0 Star	1 Star	2 Star	3 Star	4 Star	5 Star
<260	2	0	3	14	4	1
>=260	0	0	22	16	4	1
Total →	**2**	**0**	**25**	**30**	**8**	**2**

From Figure 15 it can be observed that the majority of the water-cooled chiller models lie in 2star and 3star categories.

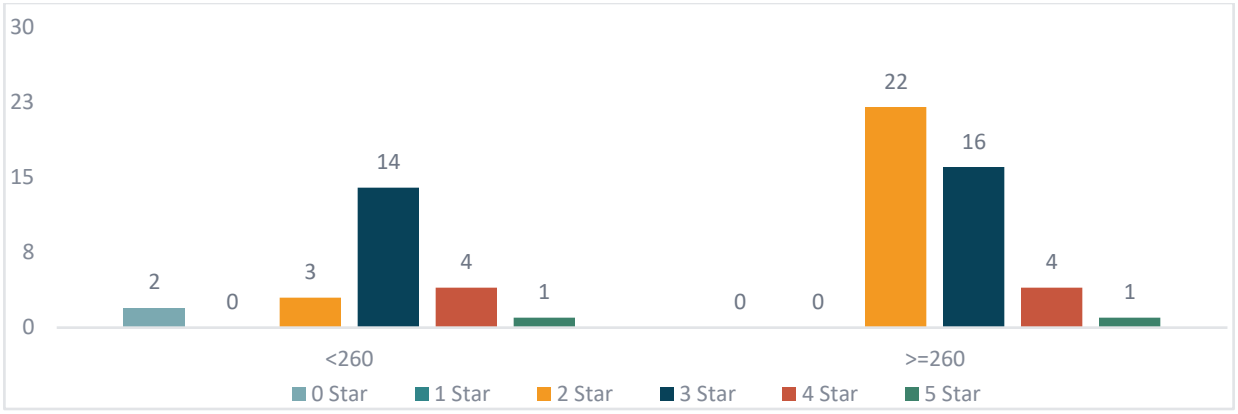

FIGURE 16 PERFORMANCE DISTRIBUTION OF AIR-COOLED CHILLERS IN THE CURRENT MARKET

4.3. OBSERVATIONS FROM TECHNICAL ASSESSMENT

As presented in the last section, a substantial improvement in the performance of chillers — both water-cooled air air-cooled — has not been observed. Additionally, the number of models reported in the survey is limited to 219. As per the stakeholder consultation, it is estimated that there are 1000+ chiller models currently being sold in the Indian market. Therefore, it is recommended that more information be collected.

4.4. WAY FORWARD FOR MANDATORY S&L

BEE released an alert on 15th September 2021[21] stating that the validity of voluntary regime S&L of chillers had been extended to 1st December 2022. The S&L program for chillers will be made mandatory from 1st July 2023. The transition to mandatory labeling regime for chiller S&L requires manufacturers to register their products under the S&L scheme. Manufacturers are obligated to display the star rating of chillers, which will enable informed purchases by consumers. Thus, BEE will be able to cover both organized- and unorganized- sector products under the labeling regime. It is expected have a direct impact on potential energy savings from the chiller program. The transition will facilitate the market towards efficient product models by eliminating models which do not meet the minimum performance requirements.

[21] https://www.beestarlabel.com/Home/ViewallAlert

5. National Impact Assessment

The national impact of the S&L program over the next 10 years can be estimated in terms of potential savings in energy consumption and reduction in GHG emissions.

The broad assumptions, calculation methodology, and potential results are discussed in detail in this chapter.

5.1. ASSUMPTIONS

1. The assessment period is 12 years i.e., FY2019 to FY2031, because the voluntary S&L program for chillers was launched in September 2018. The period from FY2019 to FY2031 is considered for assessing national impact. However, chiller sales numbers from FY2020 are used as the baseline for forecasting future sales.
2. The national impact has been estimated only for the space cooling segment of the chiller market, not the process cooling segment.
3. The forecast for water-cooled chiller market is an estimated growth of ~7.6%, and for air-cooled chillers, ~5.7% (for space cooling).
4. Different sizes of chillers are purchased in different numbers (number of units) by consumers. The capacity of chillers is reported in TR or kW and the size of the market varies for different capacity ranges.
5. Air-cooled and water-cooled chillers are segregated into 2 and 5 capacity ranges respectively[22], and the weight factor for every capacity range is estimated based on past sales. Table 15 provides the mean cooling capacity (kW) and weight factors of all the capacity ranges for water cooled chillers.

TABLE 15 WEIGTH FACTORS OF DIFFERENT CAPACITY RANGES – WATER COOLED CHILLERS (SPACE COOLING)

Sr. No.	Cooling capacity range (kW)	Mean value of the cooling capacity for every range (kW)	Average sales over last 6 years (units/year)	Weight factor (distribution based on average sales numbers over last 6 years)
	<260	(0+260)= 260	1,070	(1,070/ (1,070+291+870+232+192)) ×100= 40%
	>=260 & <530	(260+530)/2= 395	291	(291/ (1,070+291+870+232+192)) ×100= 11%
	>= 530 & <1050	(530+1050)/2= 790	870	(870/ (1,070+291+870+232+192)) ×100= 33%
	>= 1050 & <1580	(1050+1580)/2= 1,315	232	(291/ (1,070+291+870+232+192)) ×100=9%
	>=1580	1,580	192	(192/ (1,070+291+870+232+192)) ×100=7%

[22] This is based on the voluntary S&L schedule for chillers – refer to schedule 21 of BEE.

TABLE 16 WEIGTH FACTORS OF DIFFERENT CAPACITY RANGES – AIR COOLED CHILLERS (SPACE COOLING)

Sr. No.	Cooling capacity range (kW)	Mean value of the cooling capacity for every range (kW)	Average sales over last 6 years (units/year)	Weight factor (distribution based on average sales numbers over last 6 years)
	<260	260	2,496	65%
	>=260	260	1,316	35%

6. The weight factors defined in Table 15 and Table 16 helps in determining the cooling capacity of the representative model that used to evaluate energy savings.

7. The ISEER values at 2-star level in the voluntary S&L program (refer Table 4 &Table 5 in this report) are used as performance baselines for both air-cooled and water-cooled chillers.

8. A total of one hundred and fifty two (152) water-cooled chiller models are reported in the market assessment, and these models have been segregated across the 5 cooling capacity ranges[23]. Any improvement in ISEER of these chillers is determined by evaluating the average of ISEER of chiller models reported in the technical assessment for each of the 5 capacity ranges. Table 17 presents the baseline ISEER and the improved ISEER for all the capacity segments for water-cooled chillers for the period FY2019 to FY2027. Improvement in performance over baseline and the weight factors from Table 17 are used to determine the weighted average energy savings for water-cooled chillers for the period FY2019 to FY2027.

TABLE 17 BASELINE PERFORMANCE AND ESTIMATED IMPROVEMENT FOR WATER COOLED CHILLERS (FOR THE PERIOD FROM FY2019 TO FY2027)

Sr. No.	Cooling capacity range (kW)	Baseline ISEER (2 Star level) Ref. from Table 4	Improved ISEER (Market representative average of ISEER of reported models)	Improvement in performance over baseline	Weight factor (distribution based on average sales numbers over last 6 years). Refer Table 15
	<260	5.2	6.0	((6-5.2)/5.2) * 100 =16%	40%
	>=260 & <530	5.6	6.7	((6.7-5.6)/5.6) * 100 = 20%	11%
	>= 530 & <1050	6.1	6.7	((6.7-6.1)/6.1) * 100 = 10%	33%
	>= 1050 & <1580	6.5	7.2	((7.2-6.5)/6.5) * 100 = 10%	9%
	>=1580	6.7	7.5	((7.5-6.7)/6.7) * 100 = 12%	7%

[23] The capacity ranges are defined in voluntary S&L program of chillers – schedule 21 of BEE.

9. Table 18 presents the baseline ISEER and the improved ISEER for 2 capacity ranges of air-cooled chillers for the period FY2019 to FY2027. The improvement in performance over baseline and the weight factors from Table 18 are used to determine the weighted average energy savings for air-cooled chillers for the period FY2019 to FY2027.

TABLE 18 BASELINE PERFORMANCE AND ESTIMATED IMPROVEMENT FOR AIR COOLED CHILLERS (FOR PERIOD FY2019 TO FY2027)

Sr. No.	Cooling capacity range (kW)	Baseline ISEER (2 Star level) Ref. from Table 5	Improved ISEER (Market representative average of ISEER of reported models)	Improvement in performance over the baseline	Weight factor (distribution based on average sales numbers over last 6 years). Refer Table 16
1.	<260	3.3	3.9	((3.9-3.3)/3.3) * 100 = 18%	65%
2.	>=260	3.5	3.9	((3.9-3.5)/3.5) * 100 =11%	35%

10. It is assumed that chillers are used for 12 hours per day, for a total of 200 days in a year.

11. It is assumed that the service life of a chiller is 15 years.

12. The voluntary phase for S&L of chillers is until the end of the year 2022[24]. In the voluntary phase, the penetration of star labeled chillers in the market is assumed to be 5%, 10%, 15%, 25%, and 40% for the years FY2019, FY2020, FY2021, FY2022, and FY2023 respectively. Beyond FY2023, the penetration of star labeled chillers is assumed to be 100% because it is expected that S&L of chillers will be made mandatory from the beginning of the year 2023[25].

13. It is assumed that the S&L of chillers will be ratcheted up from the beginning of the year 2027. Beyond FY2027, because of the ratcheting up of the S&L program, the performance of chillers in each capacity ranges are assumed to meet the current 5-star ISEER levels. Table 19 presents the baseline ISEER and the improved ISEER for all capacity segments for water-cooled chillers for the period FY2027 to FY2031. The improvement in performance over baseline and the weight factors from Table 19 are used to determine the weighted average energy savings for water-cooled chillers for the period FY2027 to FY2031.

TABLE 19 BASELINE PERFORMANCE AND ESTIMATED IMPROVEMENT FOR WATER COOLED CHILLERS (FOR PERIOD FY2027 TO FY2031)

Sr. No.	Cooling capacity range (kW)	Baseline ISEER (2 Star level) Ref. from Table 4	Improved ISEER after ratcheting up of the S&L thresholds (5 Star level) Ref. from Table 4	Improvement in performance over the baseline	Weight factor (distribution based on average sales numbers over last 6 years). refer Table 15.

[24] Based on the BEE's notification

[25] Reference: Stakeholders' discussion during the technical committee meeting held in February 2022.

	<260	5.2	6.6	((6.6-5.2)/5.2) * 100=27%	40%
	>=260 & <530	5.6	7.4	((7.4-5.6)/5.6) * 100=32%	11%
	>= 530 & <1050	6.1	8.2	((8.2-6.1)/6.1) *100=34%	33%
	>= 1050 & <1580	6.5	8.7	((8.7-6.5)/6.5) *100=34%	9%
	>=1580	6.7	9	((9-6.7)/6.7) * 100=34%	7%

14. Table 20 presents the baseline ISEER and the improved ISEER for air-cooled chillers for the period FY2027 to FY2031. Improvement in performance over baseline and weight factors from Table 20 are used to determine the weighted average energy savings for air-cooled chillers for the period FY2027 to FY2031.

TABLE 20 BASELINE PERFORMANCE AND ESTIMATED IMPROVEMENT FOR AIR COOLED CHILLERS (FOR PERIOD FY2027 TO FY2031)

Sr. No.	Cooling capacity range (kW)	Baseline ISEER (2 Star level) Ref. from Table 5	Improved ISEER after ratcheting up of the S&L thresholds (5 Star level) Ref. from Table 5	Improvement in performance over the baseline	Weight factor (distribution based on average sales numbers over last 6 years). Refer Table 16
1.	<260	3.3	4.4	((4.4-3.3)/3.3) * 100=34%	65%
2.	>=260	3.5	4.7	((4.7-3.5)/3.5) * 100=33%	35%

5.2. METHODOLOGY

Step-1: Calculating the cooling capacity of representative chiller models

The chiller market is segmented into 2 categories — water-cooled chillers and air-cooled chillers. The cooling capacities of the representative model in each category are determined by summing the product of mean cooling capacity from each capacity range with the respective weight factors. For example, referring to Table 15 for water cooled chillers the representative capacity is calculated as follows:

(260*0.74) + (395*0.05) + (790*0.14) + (1315*0.04) + (1580*0.03) = 636 kW

However, for air-cooled chillers, the representative capacity is 260 kW because there are only two segments.

Step-2: Determining percentage savings due to improvement in performance of chillers

For the period FY2019 to FY2027

Savings percentages are determined separately for water-cooled and air-cooled chillers. The savings percentage is calculated by summing the product of improvement in performance for each capacity range with their respective weight factors. For example, referring to Table 17 for water cooled chillers the percentage of energy savings is calculated as follows:

(16%*0.40) + (20%*0.11) + (10%*0.33) + (10%*0.09) + (12%*0.07) = 14%.

Similarly for air-cooled chillers (refer to Table 18), the percentage savings is calculated as follows:

(18%*0.65) + (11%*0.35) = 16%

However, to be on the conservative side, the energy savings is considered to be **12%** for both water- and air-cooled chillers for the period FY2019 to FY2027.

For the period beyond FY2027 to FY 2031

Beyond FY2027, because of ratcheting up of the S&L program, it is assumed that the performance of chillers in each capacity range will meet current 5-star ISEER levels. Because of this ratcheting up, the performance of chillers sold in the market will increase, resulting in higher energy savings.

Referring to Table 19 the percentage savings for water cooled chillers is calculated as follows:

(27%*0.40) + (32%*0.11) + (34%*0.33) + (34%*0.09) + (34%*0.07) = 31%.

Similarly for air cooled chillers, referring to Table 20 the percentage savings is calculated as follows:

(34%*0.65) + (33%*0.35) = 34%

However, to be on the conservative side the energy savings is considered to be 20% for both water- and air-cooled chillers for the period beyond FY2027 to FY2031.

Step-3: Determining annual energy use for one chiller

The annual energy use per chiller is calculated by multiplying the representative capacity (kW) with the number of usage days in a year and the number of hours in a day.

For water-cooled chillers it is = [(636/3.517) * 0.64] kW * 200 * 12hours = 278,400 kWh

For air-cooled chillers it is = [(260/3.517) * 1.17] kW * 200 * 12hours = 206,400 kWh

Step-4: Determining surviving stock of chillers

For estimating cumulative energy savings, it is required to determine the surviving stock of chillers. This helps in understanding the installed stock at a given point in a future period.

The CLASP Product Policy Analysis Tool (PPAT) is used for estimating the surviving stock. The tool uses estimated yearly sales and the average life of an appliance as inputs for calculating the surviving stock. As already depicted in Table 9, the market is forecasted (in terms of units per year) by considering a year-on-year growth of 7.6% for water-cooled and 5.7% for air-cooled chillers (with sale in FY2020 used as baseline). The lifetime of a chiller is considered to be 15 years. This is for the space cooling chiller segment. The survival stock distribution is tabulated in Table 21 and Table 22 for water-cooled and air-cooled chillers respectively.

For example, the surviving stock by the end of 2025 (column-wise), will comprise 98.6%, 99.2%, 99.5%, 99.7%, and 99.9% of chillers sold in the years (row-wise) 2021, 2022, 2023, 2024 and 2025 respectively. Similarly, in further years, some percentage of chillers from the previous years will accumulate (survive) and some will retire.

Step-5: Determining the energy savings at a national level

The annual energy use by one chiller (that is determined in step-3) is multiplied with the installed stock of star labelled chillers (that is determined in step-4). This is further multiplied with the savings percentage (that is determined in step-2) to obtain the total annual energy savings.

Yearly energy savings and cumulative energy savings are separately evaluated for water-cooled and air-cooled chillers. They are tabulated in Table 23 and Table 24.

5.3.

5.4. TABULATION AND GRAPHICAL REPRESENTATION OF STOCK AND ENERGY SAVINGS

TABLE 21 SURVIVAL STOCK DISTRIBUTION OF WATER-COOLED CHILLERS (SPACE COOLING)

				↓Years for which the survival stock is forecasted (water cooled chillers) ↓												
S&L penetration (in terms of percentage of market)	Estimated Sales (5.8% YoY growth) (number of units)	Estimated Sales of Star Labelled products (number of units)	Forecast year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
5%	3,239	162	**2019**	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %	96.4 %	94.5 %	91.9 %	88.5 %	84.1 %	78.8 %	72.6 %
10%	2,876	288	**2020**	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %	96.4 %	94.5 %	91.9 %	88.5 %	84.1 %	78.8 %
15%	3,096	464	**2021**	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %	96.4 %	94.5 %	91.9 %	88.5 %	84.1 %
25%	3,332	833	**2022**	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %	96.4 %	94.5 %	91.9 %	88.5 %
40%	3,586	1,434	**2023**	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %	96.4 %	94.5 %	91.9 %
100%	3,860	3,860	**2024**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %	96.4 %	94.5 %
100%	4,154	4,154	**2025**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %	96.4 %
100%	4,471	4,471	**2026**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %	97.7 %
100%	4,813	4,813	**2027**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %	98.6 %
100%	5,180	5,180	**2028**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %	99.2 %
100%	5,575	5,575	**2029**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %	99.5 %
100%	6,001	6,001	**2030**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %	99.7 %

100%	6,459	6,459	**2031**	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	99.9 %
Total stock of chillers (number of units)				3,235	6,103	9,184	12,490	16,032	19,819	23,858	28,152	32,702	37,503	42,551	47,838	53,359
Surviving stock of star labelled chillers (number of units)				162	449	912	1,742	3,170	7,017	11,148	15,579	20,326	25,402	30,816	36,576	42,683

TABLE 22 SURVIVAL STOCK DISTRIBUTIONOF FUTURE SALES – AIR COOLED CHILLERS (SPACE COOLING)

				↓Years for which the survival stock is forecasted (air cooled chillers) ↓												
S&L penetration (in terms of percentage of market)	Estimated Sales (4.8% YoY growth) (number of units)	Estimated Sales of Star Labelled products (number of units)	Forecast year	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
5%	4,474	224	**2019**	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%	96.4%	94.5%	91.9%	88.5%	84.1%	78.8%	72.6%
15%	4,045	405	**2020**	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%	96.4%	94.5%	91.9%	88.5%	84.1%	78.8%
20%	4,276	641	**2021**	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%	96.4%	94.5%	91.9%	88.5%	84.1%
25%	4,519	1,130	**2022**	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%	96.4%	94.5%	91.9%	88.5%
40%	4,777	1,911	**2023**	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%	96.4%	94.5%	91.9%
100%	5,049	5,049	**2024**	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%	96.4%	94.5%
100%	5,337	5,337	**2025**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%	96.4%
100%	5,641	5,641	**2026**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%	97.7%
100%	5,962	5,962	**2027**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%	98.6%
100%	6,302	6,302	**2028**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%	99.2%
100%	6,661	6,661	**2029**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%	99.5%
100%	7,041	7,041	**2030**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%	99.7%
100%	7,442	7,442	**2031**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.9%
Total stock of chillers (number of units)				4,468	8,502	12,758	17,241	21,957	26,906	32,084	37,482	43,084	48,870	54,814	60,888	67,066
Surviving stock of star labelled chillers (number of units)				223	627	1,267	2,392	4,295	9,326	14,631	20,219	26,094	32,259	38,709	45,435	52,420

TABLE 23 ENERGY SAVINGS FROM WATER COOLED CHILLERS (SPACE COOLING)

Year	Stock of star labeled chillers (ITY)	Estimated Savings	Energy Savings (ITY) kWh	Energy Savings (cumulative) TWh	GHG Emission Reduction (Mt CO2e)
2019	162	12%	5,412,096	0.005	0.004
2020	449	12%	15,000,192	0.020	0.017
2021	912	12%	30,468,096	0.051	0.042
2022	1,742	12%	58,196,736	0.109	0.089
2023	3,170	12%	105,903,360	0.215	0.176
2024	7,017	12%	234,423,936	0.449	0.369
2025	11,148	12%	372,432,384	0.822	0.674
2026	15,579	12%	520,463,232	1.342	1.101
2027	20,326	20%	1,131,751,680	2.474	2.029
2028	25,402	20%	1,414,383,360	3.888	3.189

2029	30,816	20%	1,715,834,880	5.604	4.596
2030	36,576	20%	2,036,551,680	7.641	6.265
2031	42,683	20%	2,376,589,440	10.017	8.214

TABLE 24 ENERGY SAVINGS FROM AIR COOLED CHILLERS (SPACE COOLING)

Year	Stock of star labeled chillers (ITY)	Estimated Savings	Energy Savings (ITY) kWh	Energy Savings (cumulative) TWh	GHG Emission Reduction (Mt CO2e)
2019	223	12%	5,523,264	0.006	0.005
2020	627	12%	15,529,536	0.021	0.017
2021	1,267	12%	31,381,056	0.052	0.043
2022	2,392	12%	59,245,056	0.112	0.092
2023	4,295	12%	106,378,560	0.218	0.179
2024	9,326	12%	230,986,368	0.449	0.368
2025	14,631	12%	362,380,608	0.811	0.665
2026	20,219	12%	500,784,192	1.312	1.076
2027	26,094	20%	1,077,160,320	2.389	1.959
2028	32,259	20%	1,331,651,520	3.721	3.051
2029	38,709	20%	1,597,907,520	5.319	4.362

2030	45,435	20%	1,875,556,800	7.194	5.899
2031	52,420	20%	2,163,897,600	9.358	7.674

5.5. POTENTIAL IMPACT

The total potential energy savings (for space cooling segment) is the summation of energy savings due to water-cooled chillers and air-cooled chillers. The total energy and GHG savings are tabulated in Table 25.

TABLE 25 ENERGY AND GHG SAVINGS (SPACE COOLING)

Cumulative Energy savings from water cooled chillers for a period of 2019-2031	TWh	10.0
Cumulative Energy savings from air cooled chillers for a period of 2019-2031	TWh	9.3
Total energy savings	**TWh**	**19.3**
Grid emission factor	tCO2/MWh	0.82
GHG emission reduction	tCO2	15,888,151
GHG emission reduction	**Mt CO2e**	**15.9**

The potential energy and GHG emission savings are represented in the charts below.

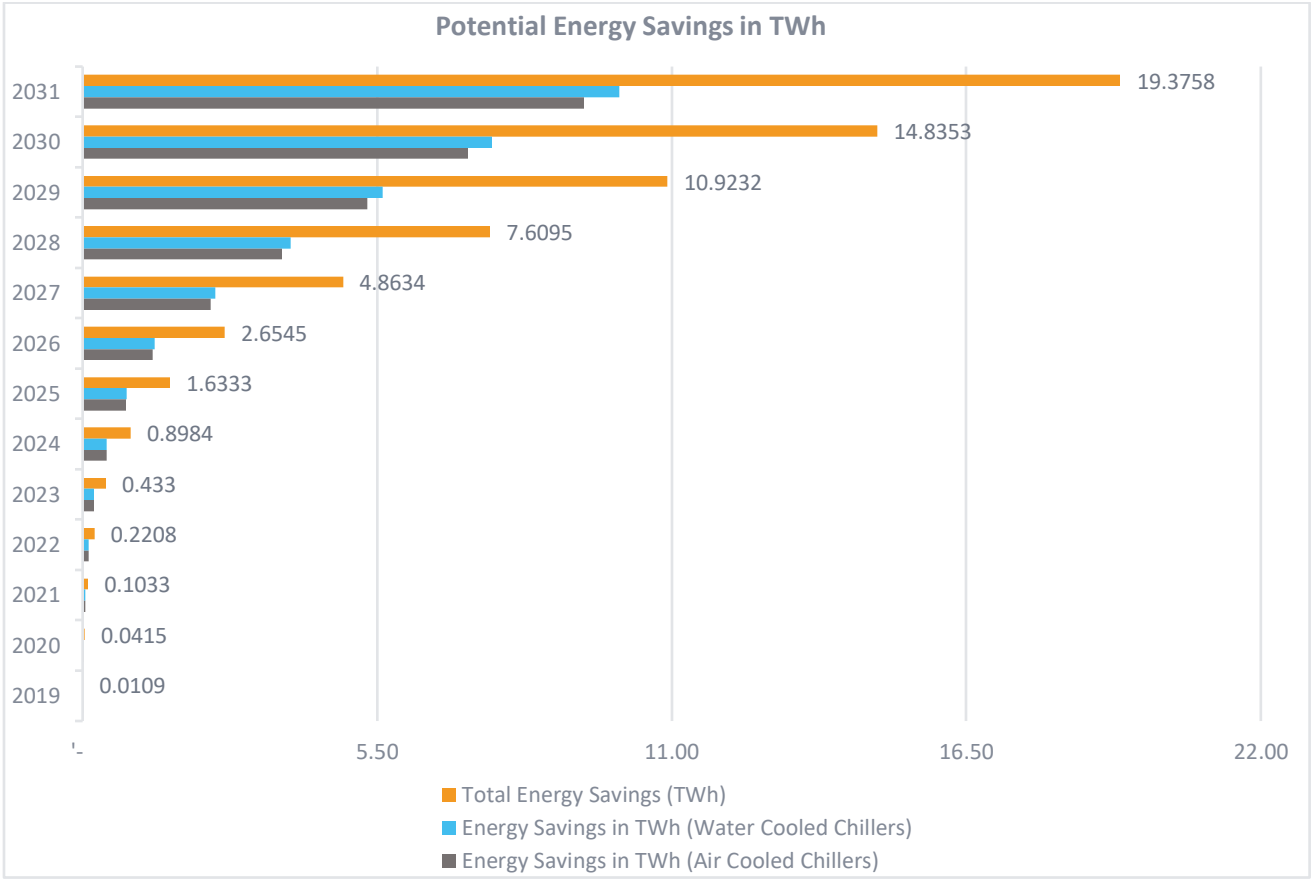

FIGURE 17 POTENTIAL ENERGY SAVINGS

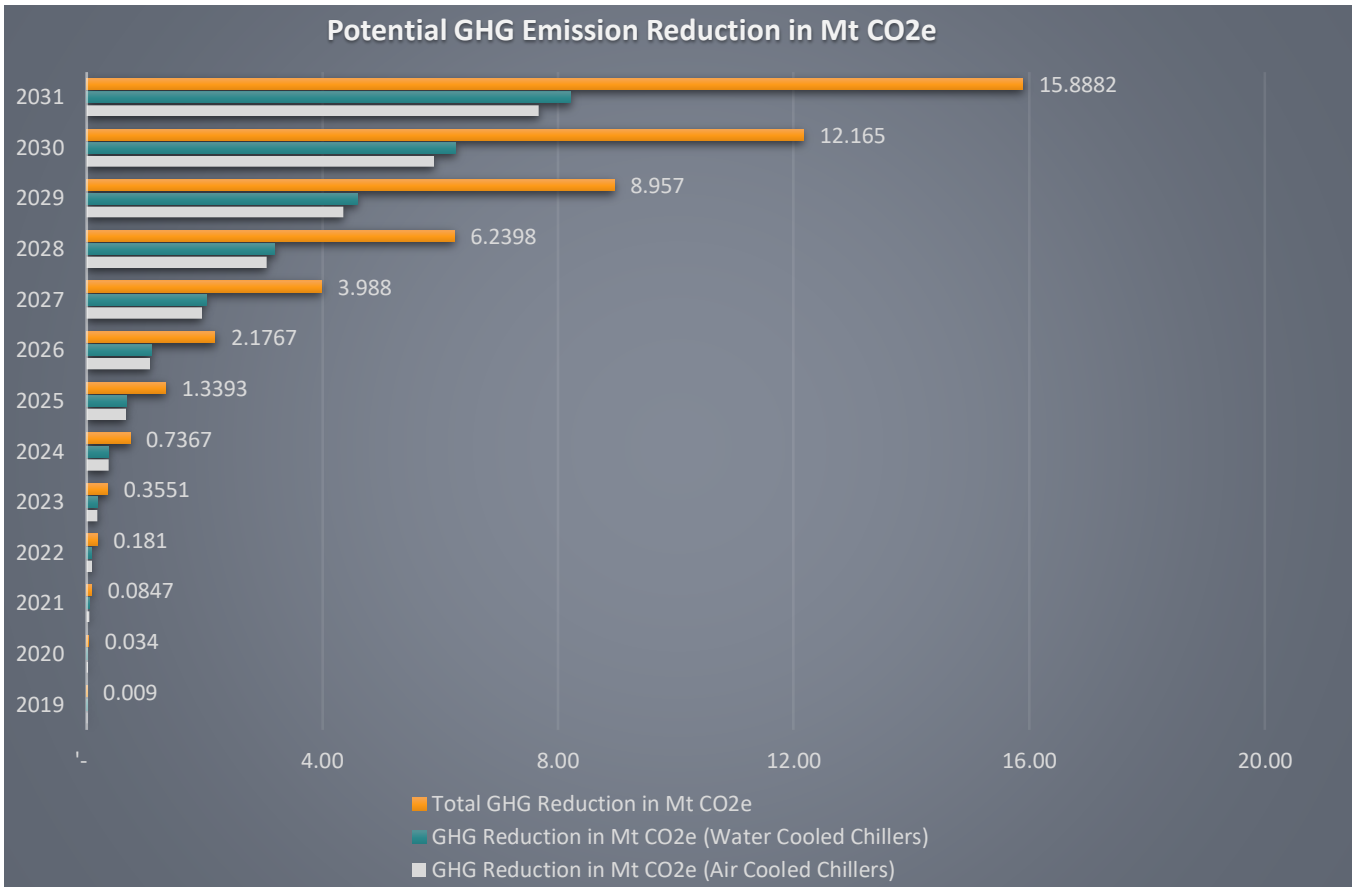

FIGURE 18 POTENTIAL GHG EMISSION REDUCTION

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Endnotes