

Market Assessment of Multi-split Air Conditioning Systems in the Chinese and Global Market

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Executive Summary

Commercial air conditioning systems present a key opportunity for reducing greenhouse gas emissions by reducing fossil fuel-based electricity consumption through improved efficiency and through transitioning to refrigerants with low greenhouse gas warming potential (GWP). In particular, variable refrigerant flow (VRF) is a rapidly growing category of multi-split air conditioning (AC) systems that now accounts for a quarter and more than half of the global and Chinese markets, respectively. This report reviews the multi-split AC market in China and its key demand growth drivers, followed by a detailed market assessment of the Chinese multi-split market by size and capacity, by efficiency levels, and by manufacturers. A summary of the global market and recent technology trends and refrigerant choices is also provided to inform revision of the 2008 China minimum energy performance standards (MEPS) for multi-connected AC equipment and revision of MEPS for multi-connected AC equipment globally.

China's commercial air conditioning market is driven by the country's economic growth, strong real estate market and rebounding construction market. VRFs are increasingly replacing chillers, and are also driven by demand from expanding home improvement and furnishing sales, e-commerce platforms and growing demand from younger generations of homeowners. The regional distribution of VRF sales remain fairly steady, with half of the sales coming from the economically developed Eastern coastal region which still has significant potential for growth, followed by the hot and tropical Southern region. North and Central China together accounts for another quarter of sales. In terms of specific end-use sectors, East China dominates in terms of residential, office and commercial AC demand, while North and South China face stronger demand for commercial ACs than residential ACs. As a result of these demand drivers, VRFs have grown from the second largest product category amongst packaged multi-split AC products in terms of market value, with 11% market share in 2015 growing to 50.3% market share in 2017 with total market value of 40 billion RMB. After VRFs, chillers and unitary ACs are the second and third largest product categories.

For both residential and commercial multi-split ACs, common configurations include large outdoor unit capacity with 4 or more indoor units of varying capacities. For residential VRFs, the most common configuration includes 5 indoor units with each main room of the residence (including bedrooms and living rooms) having one indoor unit while for commercial VRFs, mini-VRF system with 4 indoor units are the most common. Defining the specific number of indoor units for testing in the test methods that accompany the revised MEPS will help address possible efficiency comparability issues between models with different configurations and number of indoor units.

In terms of efficiency, China introduced its MEPS for multi-split ACs that include VRF systems in the same product category as fixed-speed, variable-speed and digital scroll units in 2008. This current MEPS applies to all units with nominal cooling capacity of 28,000 W or greater, and uses Integrated Part Load Value (IPLV) for cooling as the energy efficiency metric. Since 2012, market survey data shows that the model-weighted efficiency of all products has increased by more than 50% varying by the capacity. For variable-speed multi-split units in particular, the model-weighted average efficiency is relatively high in the range of IPLV cooling values of 7 to 8 W/W in 2015 but could include prototype models with limited availability. In 2016, however, the model-weighted average efficiency declined slightly in for the smallest cooling capacity class as some

lower efficiency multi-split models entered the market.

In the Chinese multi-split AC market, there is a significant difference in the sales distribution by energy efficiency grade as defined by the China Energy Label efficiency thresholds included in the 2008 MEPS for fixed-speed multi-split ACs versus variable-speed and digital scroll multi-split ACs. While the average efficiency of variable-speed and digital scroll multi-split units are already in the range of Grade 1 (most efficient) efficiency as defined by the 2008 MEPS, fixed-speed units are generally in the range of Grade 3 and 4 efficiency. There was little change in the sales distribution by efficiency class for all three product types. This suggests that with the exception of fixed-speed multi-splits that continue to lag in efficiency improvements, existing efficiency thresholds based on the 2008 MEPS are no longer effective in differentiating among the efficiencies of variable-speed and digital scroll multi-splits sold on the market.

In terms of the landscape for manufacturers, the Chinese multi-split AC market has historically been dominated by major Japanese brands including Daikin, Hitachi, Mitsubishi Electric, and Toshiba, which had the largest market presence and continue to show robust growth. Over the last few years, however, Japanese brands are facing growing competition from domestic Chinese manufacturers including Gree, Midea, and Haier with a combined market share of nearly 30% in 2017. The market is also seeing very small but growing shares from American brands including Johnson Controls, Carrier, Trane, and York and McQuay and European brands such as Dunham-bush and Bosch.

Globally, China has also been a key driver of global VRF sales, reaching over 1.3 million systems in 2016. In 2016, China accounted for the majority of global VRF sales with 54% share, followed by Europe, Japan, and South Korea, each with shares of around 10%. In terms of global technology trends, the highest efficiency VRF systems in the U.S. market have achieved Integrated Energy Efficiency Ratio (IEER) of over 9 W/W and Energy Efficiency Ratio (EER) of over 4 W/W for units in the 20 to 28 kW cooling capacity range. Mitsubishi Electric has also introduced the first hybrid VRF system that utilizes a hybrid branch controller to provide simultaneous heating and cooling with heat recovery, with a model introduced in May 2018 for the United Kingdom market that uses alternative, low-GWP R-32 refrigerant. Because R32 is considered a mildly flammable but safe refrigerant, research groups such as the Japan Society of Refrigeration and Air Conditioning Engineers have started to conduct risk assessments to understand the probability of fire incidents under different scenarios. Further research will help address possible safety concerns with using R32 as an alternative refrigerant for VRF systems in the future.

We conclude that:

- Demand for multi-splits is growing rapidly not only within China as a result of strong economic growth and commercial building (as well as some residential) demand for cooling services, but is also driving global VRF sales.
- Domestically, Chinese manufacturers are emerging as new players in the multi-split AC manufacturing industry.
- Market survey data show that the average energy efficiency of all three types of multi-split AC systems have far surpassed the existing 2008 MEPS efficiency requirements, suggesting that more stringent requirements are needed to reflect rapidly changing market conditions.
- Improving the stringency of multi-split AC MEPS in China will bring significant economic, energy and emissions benefits to China and globally as the Chinese multi-split market

continues to expand.

- Including specifications on the configuration and number of indoor units in the test method will help address possible variations in energy use from the varying number of indoor units between different product models.

1. Introduction

After residential cooling, commercial air conditioning units presents another key opportunity for reducing direct greenhouse gas emissions by reducing fossil fuel-based electricity consumption by reducing indirect greenhouse gas emissions through transitioning to refrigerants with low greenhouse gas warming potential (GWP). Globally, cooling accounts for about 20% of building electricity consumption (IEA, 2018). In China, cooling is estimated to account for nearly one-third of commercial building electricity consumption (LBNL, 2018).

A key technology in the global commercial air conditioning market is variable refrigerant flow (VRF) systems, which differs from other small split systems in that it includes at least one inverter-controlled variable-speed compressor that uses refrigerant to deliver heating and cooling. In recent years, VRF has accounted for nearly a quarter of the global commercial air conditioning market and in 2017, reached more than half of the Chinese commercial air conditioning market (Thornton and Wagner, 2012; CAMAR, 2018). VRF products are widely used in China, India, the European Union and Eastern Europe, with growing shares in the U.S. market as well. VRF systems include one or more outdoor compressor units that are either air-source or water-source serving multiple indoor fan coil refrigerant evaporator units.

The specific product category of commercial cooling systems analyzed in this report is the multi-split system, of which a subset of products are considered VRF systems. The specific product definitions considered in this report include:

Multi-split system: A mechanical refrigeration air conditioner or heat pump system, it consists of an outdoor compressor-containing unit, two or more indoor units to supply cooled or heated air to the space being conditioned with the outdoor and indoor units being connected by refrigerant tubing. The applications are generally commercial, but some installations occur in high-end residential buildings.

VRF Multi-split system: This system consists of equipment in which the cooling (and heating) circuits to the indoor units are operated and controlled independently, allowing individual zone control and simultaneous heating and cooling.

This report provides a market assessment of VRF and other types of multi-split cooling units including fixed-speed and digital scroll multi-split units on the Chinese market, with emphasis on the commercial air conditioning market but also recognizing residential market as a driver for VRF sales. This report also includes supplementary information on technology trends (including alternative refrigerants with low greenhouse warming potential) in the global market, to inform the revision of the 2008 China minimum energy performance standards (MEPS) for multi-connected air-conditioning (heat pump) equipment.

The rest of the report is organized as follows: Section 2 summarizes the methodology and key data sources for the market assessment, followed by an overview of the multi-split market in China and key growth drivers in Section 3. Section 4 provides detailed market assessment of the Chinese multi-split market in terms of distribution by unit size and configurations, by efficiency levels and by manufacturers. Section 5 summarizes the global market for VRFs and the latest emerging

technology trends and alternative refrigerant choices. Section 6 concludes the report with key findings and implications for the MEPS revision.

2. Methodology and Data Sources

This market assessment is based on a mix of primary and secondary data sources, including aggregate data on model registrations from the China Energy Label database, Chinese and global air conditioning industry reports. The key specific data sources of market data presented throughout this report include:

1. BSRIA Published Marketing Report on Large Packaged Air Conditioners in China: this 2016 market report by the British consulting company, BSRIA, is based on 16 in-person interviews and 22 telephone interviews with various industry stakeholders.
2. China Central Air-Conditioning Market 2017 Annual Report (in Chinese) published by Mechanical and Electrical Information for the Central Air Conditioning Market magazine: this annual industry report is based on analysis of data obtained from upstream suppliers, industries, engineering companies, and national and regional retailers.
3. 2017 Research Report on the Actual Operating Conditions of China's Air Conditioners written by Cheng Jianhong of China National Institute of Standardization (CNIS): this technical report published by CNIS is based on a technical and market sample survey of 200,000 units.

3. Market Overview and Drivers

China's commercial air conditioning market has and continues to be driven by the country's rapid economic growth and construction boom. In 2017, China's total fixed asset investment increased by 7.2% compared to 2016 levels, with notably higher year-on-year increase of 9.5% for investment in the tertiary sector. Total national investment in the Chinese commercial real estate market reached 109.8 billion RMB in 2017, growing by 7% compared to 2016 levels (MEI, 2018). This is mostly driven by rapid growth in the central and eastern regions. Alongside this continued economic growth, air conditioning penetration in the Chinese commercial sector is expected to grow from 56% in 2014 to 60% by 2018 (Chu, 2016).

Within the commercial AC sector, growth in demand for multi-split units and VRFs in particular are expected to be driven by an expanding real estate market and a rebounding construction market. VRFs are increasingly replacing chillers, which continues to face declining manufacturing market shares, in the commercial sector. Additionally, strong demand for home improvement and furnishing services, the rise of e-commerce platforms and growing demand from younger generation are also driving residential demand for small multi-split AC products (MEI, 2018).

Figure 1 below shows the geographic distribution of China's multi-split AC market, with market shares shown for each geographic region in 2016 and 2017. Overall, there has not been any notable

changes in regional distribution¹ of demand for multi-split AC. The economically developed Eastern coastal region holds nearly half of the demand for multi-split ACs in China, followed by the hot and tropical South China region. North and Central China together account for about a quarter of multi-split AC demand, with higher share of total demand from North China than Central China. From a long-term perspective, the East China region still has enormous potential for growth, with a key driver being the increasingly popular residential décor retail market (MEI, 2018).

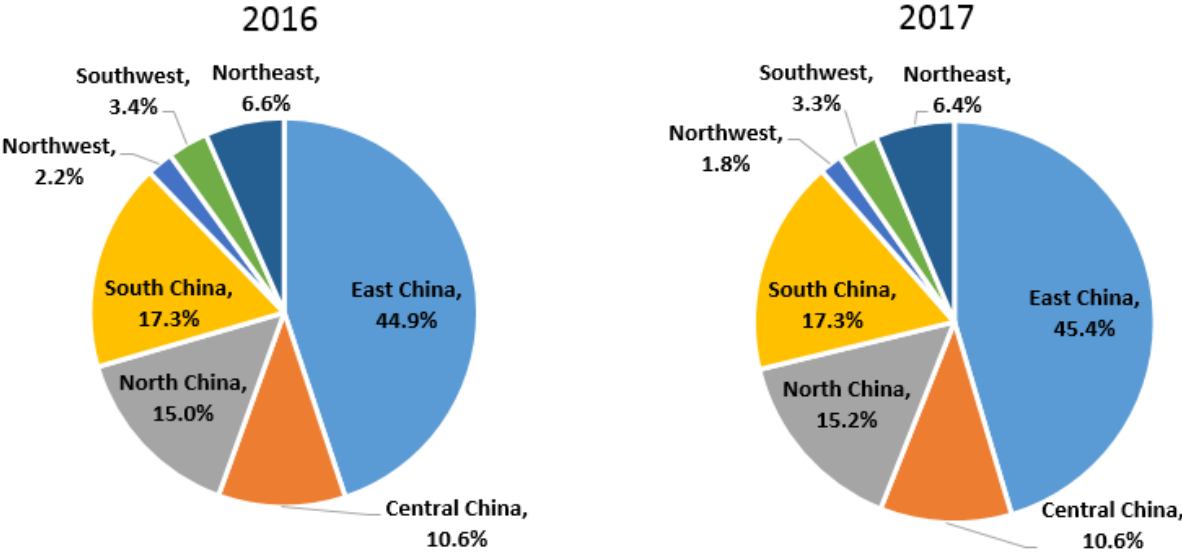


Figure 1. Regional Shares and Distribution of Multi-split AC Market

Source: MEI, 2018

In terms of demand for air conditioning products by end-use sectors, Figure 2 shows the regional shares for AC demand in residential sector, office building subsector, other commercial sectors, as well as for VRFs specifically. The regional market shares are generally similar across AC end-use sectors, with a few exceptions. The relatively affluent and rapidly growing East China region dominates in terms of regional market shares for residential AC demand, as well as office and other commercial AC demand, and VRF demand. East China accounts for between 40% to over 50% of national demand, but only accounts for 29% of national population. Within East China, the Hot Summer Cold Winter climate zone is also one of the most densely populated and economically developed regions with rapidly growing demand for cooling in summer and heating in winter for residential buildings (Zhang et al. 2018). The use of VRFs in residential buildings is also increasing in this specific climate zone because of various factors, including: high performance at part-load conditions, zonal thermal comfort control, design and appeal to consumers, ease of maintenance, and lower minimum operating temperatures that make heat pumps more appealing (Zhang et al. 2018). The high demand for cooling, particularly in residential buildings, is reflected in the much higher air conditioner ownership rates in all provinces and municipalities considered in the East China region when compared to other regions, as shown in Figure 2.

¹ Regional groupings are defined in MEI, 2018 as follows: East China includes Shanghai, Jiangsu, Zhejiang and Anhui; North China includes Beijing, Tianjin, Hebei, Shandong, Shanxi, Inner Mongolia; South China includes Guangdong, Fujian, Jiangxi, Hainan, Guangxi; Central China includes Henan, Hubei, Hunan; Southwest includes Chongqing, Sichuan, Guizhou, Yunnan; Northwest includes Shaanxi, Xinjiang, Ningxia, Gansu, Qinghai; and Northeast includes Liaoning, Jilin, Heilongjiang

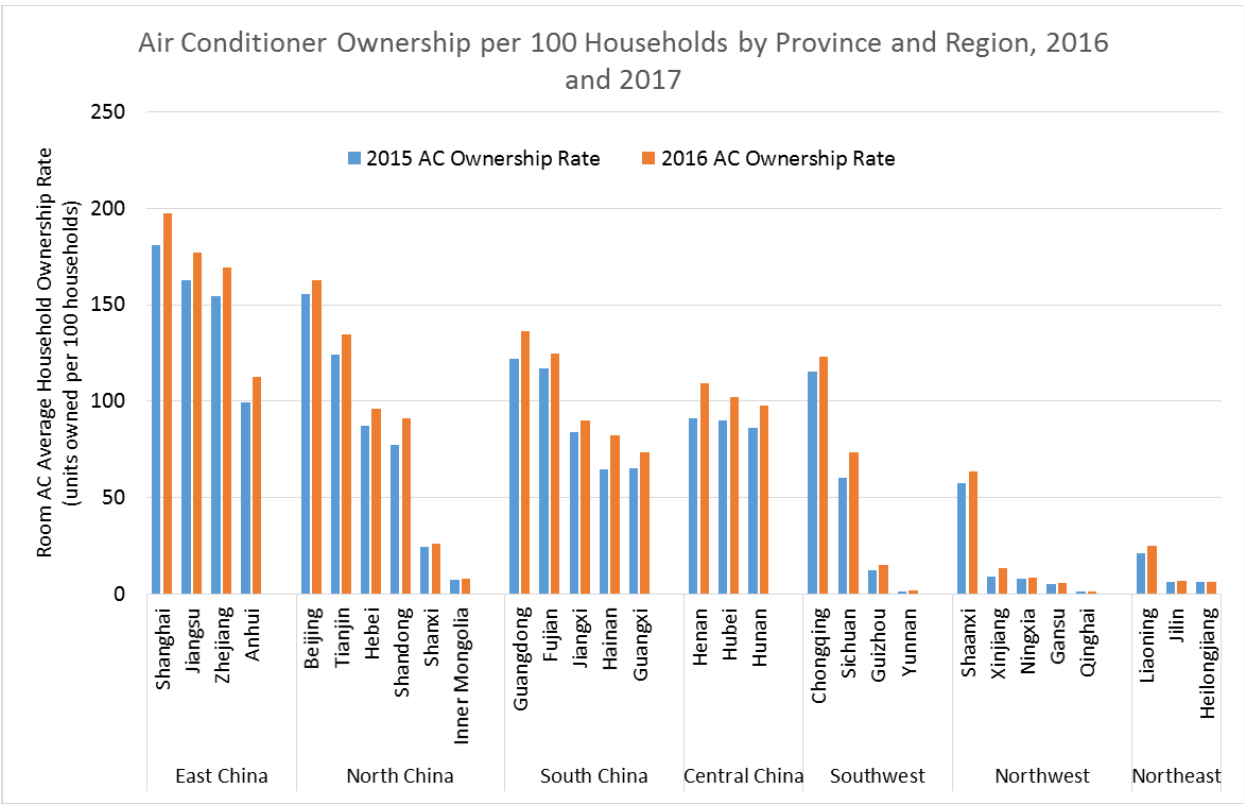


Figure 2. Average Room Air Conditioner Household Ownership Rate by Region, 2016 and 2017
 Source: data from NBS, 2018 based on regional groupings defined in MEI, 2018

However, unlike for residential AC demand, North and South China have stronger demand for commercial (including office) AC products and VRFs, with much higher market shares for these products when compared to the regional shares for residential ACs. Based on a survey of 200,000 multi-split units across China, MEI 2018 found that South China has the second largest regional share for office AC and VRF markets, but the second smallest share for residential ACs. This suggests that as economic growth continues in these regions, residential demand for ACs (including for VRFs) will likely grow as residential AC ownership continues to increase, particularly in specific provinces where household AC ownership rates are below the national average.

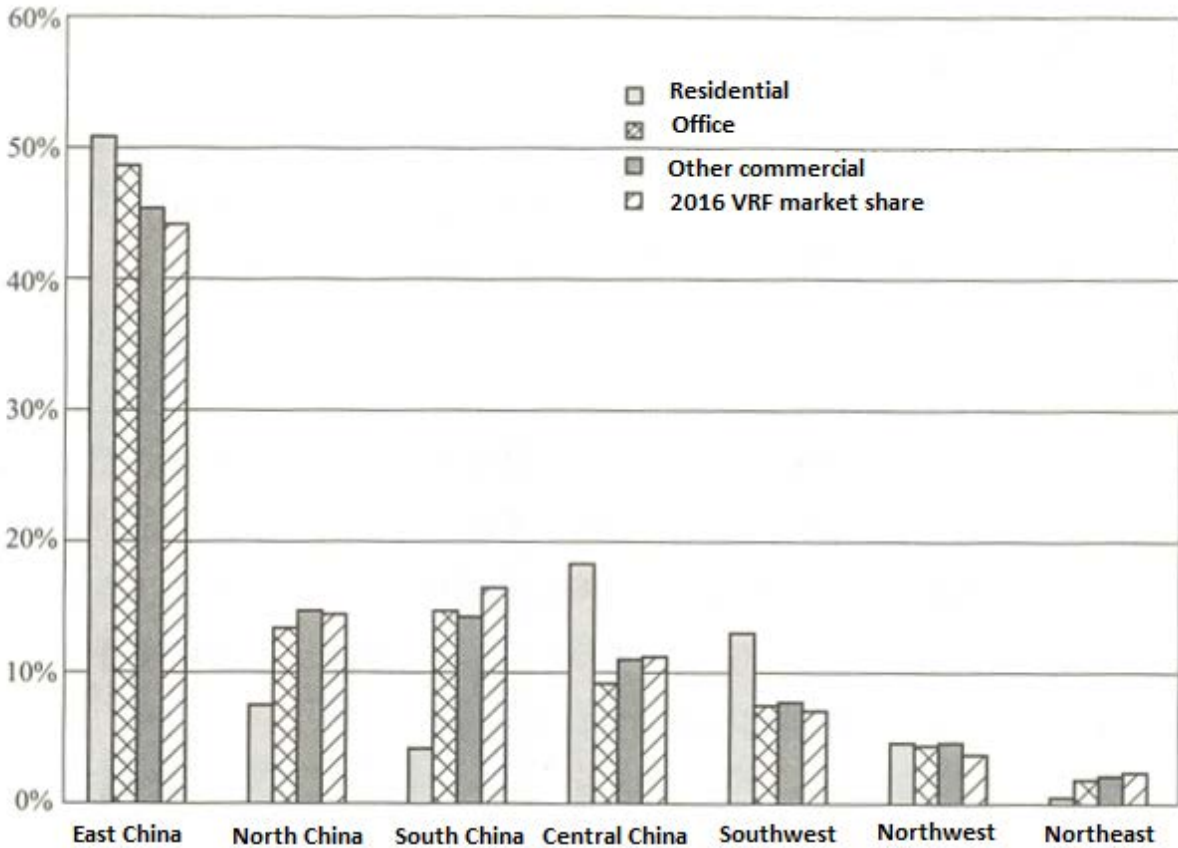


Figure 3. Comparison of 2016 Regional Shares of Demand for ACs by End-use Sectors

Source: MEI, 2018

As a result of these macroeconomic and market drivers, commercial multi-split units including VRFs have been growing rapidly over the last few years. The domestic output of multi-split ACs have increased year-on-year for every month over the last three years, with much higher output in the first four months of 2018 compared to the previous two years.

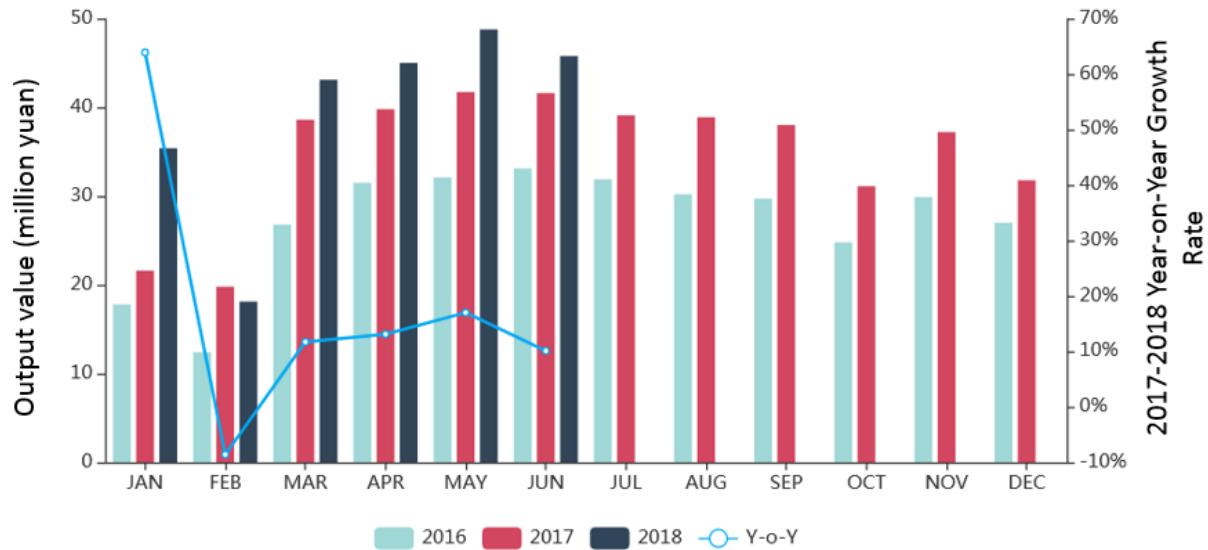


Figure 4. Monthly Chinese Commercial Multi-Split AC Production Value and Year-on-Year Growth

Source: ChinaIOL.com, 2018, <http://data.chinaiol.com/ecdata/index#>

Of all the multi-split AC product types, VRFs have been growing the fastest over the last few years. In 2015, VRFs were the second largest product in China’s large packaged and central plant market in terms of its market share by value and accounted for US\$3.6 billion market value (Chu, 2016). By volume, VRFs accounted for only 1.5% of the large packaged and central plant market² in 2015.

However, from 2015 to 2017, VRFs have undergone significant rapid growth and now accounts for more than half of the commercial AC industry in terms of market value as seen in Figure 5 below. With double-digit annual growth rates of more than 20% from 2015 to 2016, and 2016 to 2017, VRFs reached 50.3% market share of the Chinese commercial AC market, with total value of 40 billion Chinese RMB.

² Packaged and central plant products include windows, portable units, splits, indoor packaged and rooftops, chillers, air handling units, and fan coils.

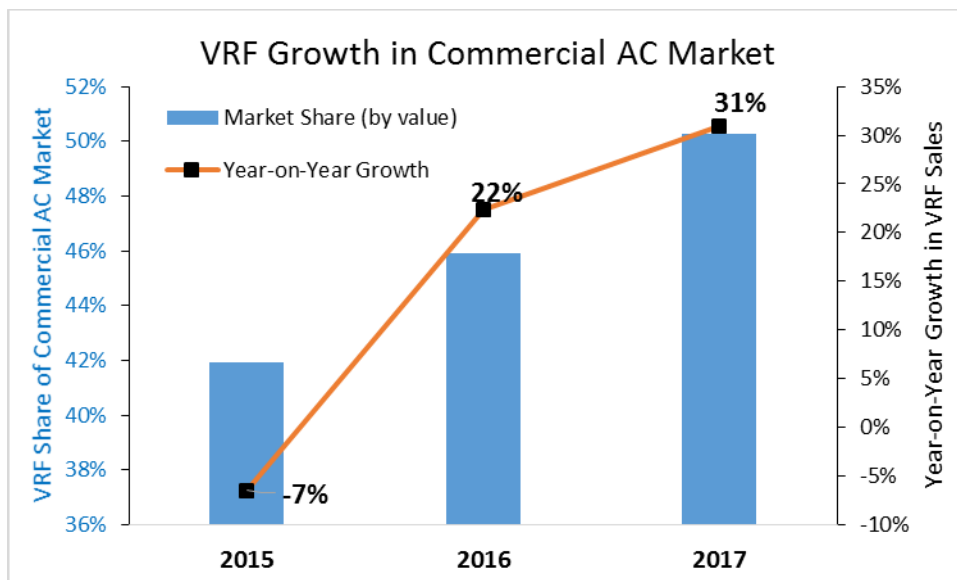


Figure 5. VRF Growth in China’s Commercial AC Market

Source: MEI, 2018

Table 1 compares the change in market shares of different commercial AC product categories from 2015 through 2017 in China, compared to VRFs. After VRFs, chillers and unitary ACs are the second and third largest product categories. However, most types of chillers except modular units are losing market shares to VRFs, along with declining shares in heat pump ACs, terminal AC units and lithium bromide AC units. The continued growth in VRF sales and market shares suggest that this product category will be the most important in influencing the future energy consumption trends of the commercial AC sector.

Table 1. Comparison of Change in Market Shares of Commercial AC Product Categories, 2015-2017

Product Category Type	Subcategory Type	2015	2016	2017	Percentage Point Change in Market Share from 2016
Chiller	Centrifuge	6.82%	6.59%	5.65%	-0.94%
	Air-cooled screw	1.58%	1.68%	1.50%	-0.18%
	Water-cooled screw	7.20%	6.03%	4.61%	-1.42%
	Modular units	6.90%	7.68%	7.76%	0.08%
VRF	Variable multi-split	41.94%	45.92%	50.27%	4.35%
Lithium bromide unit	Lithium bromide	2.48%	2.20%	1.82%	-0.38%
Water/ground source heat pump (incl. water-loop)	Water/ground source heat pump (incl. water-loop)	2.58%	2.54%	1.87%	-0.67%
Unitary unit	Unitary unit	18.60%	16.53%	16.56%	0.03%
Terminal unit	Terminal unit	9.45%	9.38%	8.58%	-0.80%

Source: MEI, 2018

The rest of this report will focus primarily on recent changes in the VRF market distribution, with in-depth analysis of VRF market distribution by capacity and unit size, by efficiency, and overview of the VRF manufacturing industry situation in China.

4. China Market Assessment

4.1 Market Distribution by Size and Configurations

As seen in Figure 6 below, most of the residential multi-split ACs have very large outdoor unit capacities, with more than half of the installed market share dominated by systems with 14 or higher kW capacity for outdoor units (Cheng, 2017).

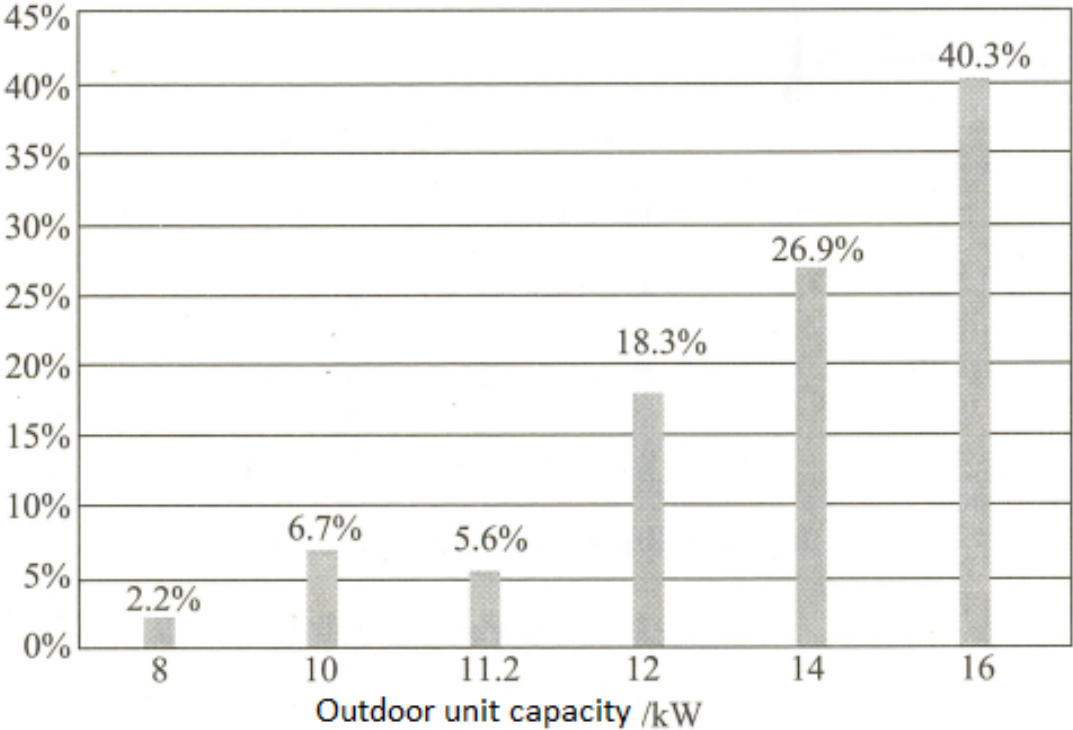


Figure 6 Distribution of installed residential multi-split capacity by capacity of outdoor units

Source: adapted from Cheng, 2017

Figure 7 shows the distribution of indoor units (IUs) configuration for common multi-split system with 16 kW outdoor unit capacity. It can be observed that most of the 16kW systems have five indoor units. For residential VRFs, residents typically install one indoor unit in each room of the residence, particularly in bedrooms and the living room. Since most urban families have three bedrooms and two common rooms (e.g., living room, dining room, kitchen) or four bedrooms and two common rooms, the most commonly installed systems include 1~1.5 horsepower IU for smaller rooms (such as bedroom and reading room) and a 2.5~3 horsepower IU or two 1.5~2.5 horsepower IUs for the common room.

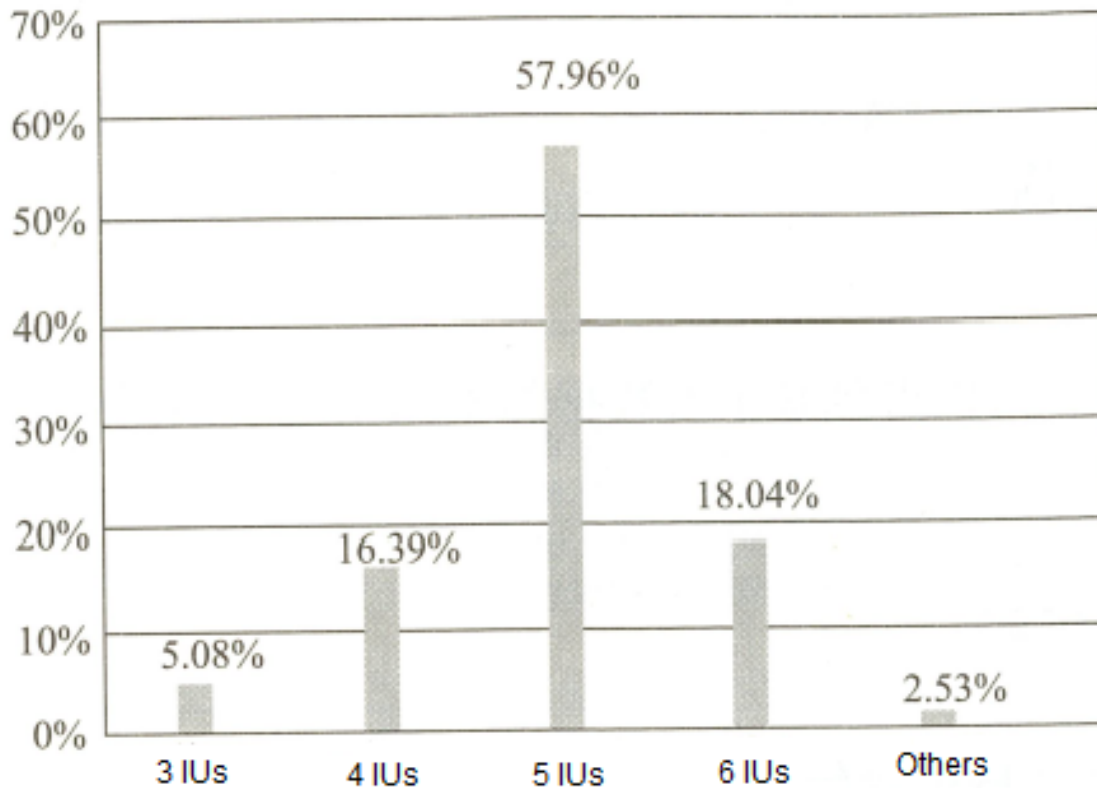


Figure 7. Distribution of Indoor Unit (IU) Configurations for 16kW VRF System

Source: adapted from Cheng, 2017

Table 2 shows the distribution shares of indoor unit configurations for a multi-split system with one outdoor unit and five indoor units, the most common residential system seen in Figure 6.

Table 2. Distribution of Indoor Unit Configurations for Common Residential VRF System with 1 Outdoor Unit, 5 Indoor Units

Outdoor Unit Capacity	Number of Outdoor Units	Indoor Unit Configurations	Percentage
16kW	5	1x3hp+2x1.5hp+2x1hp	9.48%
		1x3hp+1x2hp+1x1.5hp+2x1hp	9.42%
		1x3hp+3x1.5hp+1x1hp	7.35%
		1x2.5hp+1x2hp+2x1.5hp+1x1hp	6.82%
		1x2.5hp+1x2hp+1x1.5hp+2x1hp	6.08%
		1x3hp+1x2hp+2x1.5hp+1x1hp	5.87%
		1x2.5hp+2x1.5hp+2x1hp	5.01%
		1x2.5hp+3x1.5hp+1x1hp	4.56%
		1x3hp+1x1.5hp+3x1hp	3.79%
		1x2.5hp+2x2hp+1x1.5hp+1x1hp	3.00%
		1x3hp+4x1.5hp	2.76%
		1x3hp+2x2hp+2x1hp	2.64%
		1x3hp+1x2hp+3x1hp	2.25%
		1x2.5hp+2x2hp+2x1hp	2.22%

		2x2hp+2x1.5hp+1x1hp	2.21%
		1x2.5hp+1x2hp+3x1.5hp	2.18%
		Others	13.73%

Note: 1 horsepower (hp) =745.7W

Source: Cheng, 2017

For the commercial cooling sector, anecdotal observations from major manufacturers' experiences suggest that the most common commercial VRF systems are mini-VRF systems with 1 outdoor unit and 4 indoor units. One example of a popular mini-VRF system is Haier's system, which consists of 1 outdoor unit with 48,000 Btu/h capacity and 4 indoor units with two 9000 Btu/h units, one 12,000 Btu/h unit, and one 18,000 Btu/h unit (CSC, 2018). However, given the variation in configurations amongst existing models on the market, it would be important to include specifications related to the configuration and number of indoor units in the test method that is used to set the efficiency metrics and thresholds in the revised MEPS. This will help to ensure the variation in energy use from varying number of indoor units is addressed, and ensure comparability in efficiency between models on the market and the efficiency thresholds defined in the revised MEPS.

4.2 Market Distribution by Efficiency

China's minimum energy performance standard with mandatory energy information labeling efficiency thresholds for Grade 1 (most efficient) to Grade 5 (least efficient) for multi-splits that include VRF systems was adopted in 2008. In this GB 21454-2008 standard, all multi-split systems are categorized in the same product category, and include fixed-speed, variable-speed and digital-scroll multi-split units. The efficiency metric is Integrated Part Load Value (IPLV) for cooling, which describes the energy performance of an air conditioner under part-load conditions.

Table 3. China's Current MEPS and Mandatory Energy Label Efficiency Thresholds for Multi-split Systems

	IPLV (C) Level [W/W]				
	Grade 5 (MEPS)	Grade 4	Grade 3	Grade 2	Grade 1
CC≤28,000	2.80	3.00	3.20	3.40	3.60
28,000<CC≤84,000	2.75	2.95	3.15	3.35	3.55
CC>84,000	2.70	2.90	3.10	3.30	3.50

Source: GB 21454-2008

4.2.1 Model-weighted distribution by energy efficiency

Since the adoption of the 2008 MEPS, the model-weighted efficiency of all products produced in China has continued to increase from 2012 through 2016 across the three main cooling capacity groups based on recent market survey data presented in Cheng, 2017. For the smallest units with cooling capacity less than 28 kW, the model-weighted efficiency of surveyed products based on the metric of average Integrated Part Load Value (IPLV) used in the standard increased by 53% from

4.77 W/W in 2012 to 7.31 W/W in 2016. For larger units, the efficiency improvement amongst surveyed products was slightly greater, with IPLV increasing by 65% from 5.0 W/W in 2012 to 8.23 W/W in 2016 for units with cooling capacity of between 28 kW and 84 kW, and increasing by 64% from IPLV of 4.83 W/W in 2012 to 7.92 W/W in 2016 for units with cooling capacity greater than 84 kW. The incremental improvements in model-weighted average IPLV across these three capacity groups are shown in Figure 8.

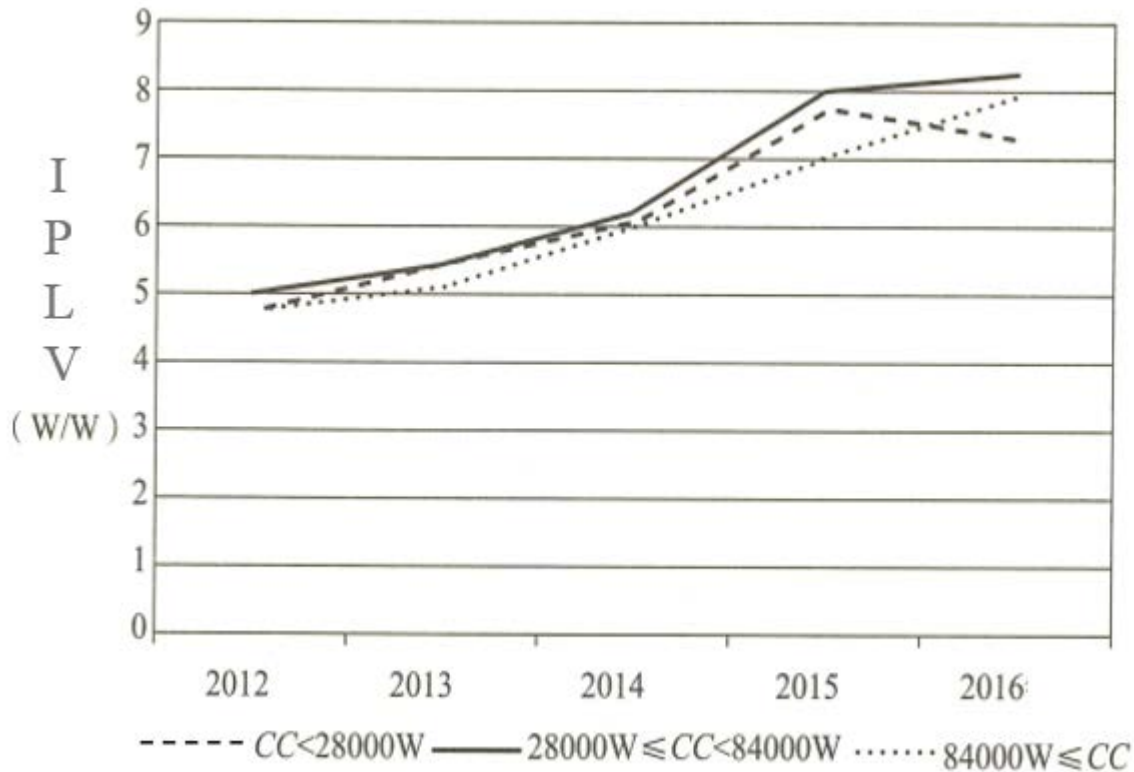


Figure 8. 2012-2016 Model-weighted Average IPLV for Multi-split ACs, in W/W

Source: adapted from Cheng, 2017

Table 4 details the 2015 and 2016 model-weighted average IPLV efficiency values as well as the minimum and maximum IPLV values of variable-speed multi-split models on the Chinese market. As seen in the table, there is a wide range of IPLVs, particularly on the low-end of efficiency values, of the models available on the Chinese market. From 2015 to 2016, the lowest IPLV value (i.e., least efficient) of models registered on the market actually dropped for two of the three capacity classes, from 4.6 W/W to 3.95 W/W for units with cooling capacity of less than 28 kW, and from 4.8 to 3.56 W/W for units with cooling capacity greater than 84 kW. For units with cooling capacity of less than 28 kW, there was also a decline in the model-weighted average efficiency between 2015 and 2016, with the average IPLV dropping from 7.75 W/W in 2015 to 7.31 W/W in 2016. This suggests that for unknown reasons, even lower efficiency multi-split models entered the market in 2016.

Table 4. 2015 and 2016 Average Energy Efficiency Level of Chinese Variable-speed Multi-split Models

			CC≤28000W	28000W<CC≤84000W	CC>84000W
IPLV (W/W)	2015	Min	4.60	4.80	5.00
		Model-weighted Average	7.75	7.95	7.10
		Max	9.50	9.20	7.55
	2016	Min	3.95	3.56	6.00
		Model-weighted Average	7.31	8.23	7.92
		Max	9.50	9.20	8.55
	2008 MEPS	Grade 5/MEPS requirement	2.80	2.75	2.70

Source: Cheng, 2017

It should be noted that the model-weighted average efficiencies included in the survey data may include very high-efficiency prototype models registered in the China Energy Label database that may have limited availability on the market. In addition, the energy efficiency levels of VRF units are only directly comparable between models with the same indoor unit configurations, but there is currently no data on indoor unit configurations in the China Energy Label database. Nevertheless, the general trend shown by the survey data on model-weighted average efficiencies and the presence and availability of higher efficiency variable-speed models across all three capacity classes on the Chinese suggest that the current market has moved far beyond the current MEPS levels.

One challenge is that the current MEPS sets the same minimum efficiency equipment for three product types of fixed-speed, digital scroll and variable-speed multi-split units, and more efficient variable-speed units face the same efficiency requirements as less efficient fixed-speed units. This suggests that having more ambitious MEPS requirements and potentially a separate product category MEPS for variable-speed multi-splits can help ensure the revised MEPS requirements are effective and accurately reflect current market situations. Based on the current MEPS, depending on the capacity class size, there is significant technical improvement potential of up to or even beyond IPLV values of 7-8 W/W for variable-speed multi-splits, from the current MEPS IPLV requirements of 2.7 – 2.8 W/W.

4.2.2 Sales-weighted distribution by energy efficiency

In the Chinese multi-split AC market, there is a significant difference in the sales distribution by energy efficiency grade as defined by the China Energy Label efficiency thresholds included in the 2008 MEPS for fixed-speed multi-split ACs versus variable-speed and digital scroll multi-split ACs. Specifically, Grade 1 represents the most efficient products with Grade 5 representing the least efficient products as defined specifically by the MEPS efficiency requirement, and Grade 1 and 2 considered efficient products under the voluntary efficiency certification program.

Table 5 compares the sales-weighted efficiency levels of variable-speed, digital scroll and fixed-speed multi-split AC units on the Chinese market in 2015 and 2016 based on an assumed average

efficiency represented by the model's energy efficiency grade. Because no specific IPLV values were available by sales, models were assigned the minimum rated efficiency for the efficiency grade the model was rated at. For example, a Grade 1 model would be assigned a representative IPLV efficiency level of 3.6. Thus, while the average efficiency of variable-speed and digital scroll multi-split units are already in the range of Grade 1 efficiency as defined by the 2008 MEPS, fixed-speed units are generally in the range of Grade 3 and 4 efficiency. More detailed market distribution of these products by efficiency grade are discussed below.

Table 5. 2015 and 2016 Sales-weighted Average Efficiency Level of Chinese Multi-split Systems by Product Subcategory

Sales-weighted Efficiency		Variable-speed	Digital Scroll	Fixed-speed
Cooling Integrated Value (制冷综合性能系数) [W/W]	2015	3.6	3.50	2.90
	2016	3.6	3.55	3.30

Source: Cheng, 2017

For fixed-speed multi-split ACs, most of the products sold in both 2015 and 2016 are the lower energy efficiency grades, with the majority of sales belonging to Grade 3 and Grade 4 products. Despite a slight increase in the share of Grade 2 products sold from around 10% in 2015 to 11.5% of the market in 2016, there are no sales for highly efficient Grade 1 fixed-speed multi-split ACs. The relatively slow increase in Grade 2's share of fixed-speed multi-split AC sales over the last five years is also shown in Figure 10. Nevertheless, the sales-weighted efficiency of fixed-speed multi-split ACs has also improved over time and is now higher than the MEPS IPLV requirements of 2.7 – 2.8 W/W for the different capacity classes.

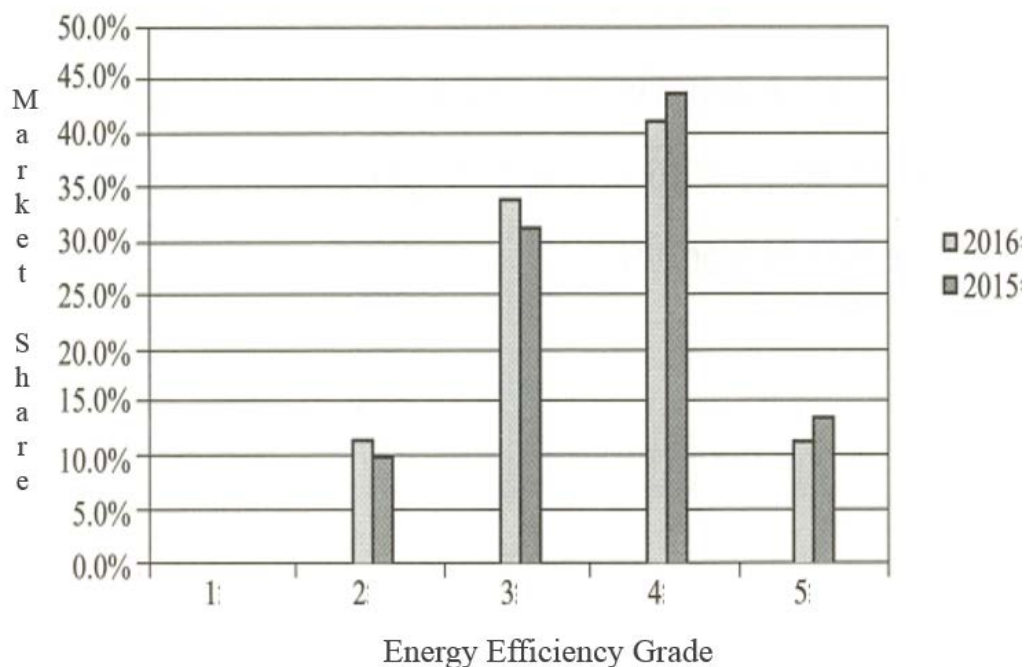


Figure 9. 2015 and 2016 Fixed-speed Multi-split AC Sales Distribution by Energy Efficiency Grade

Source: adapted from Cheng, 2017

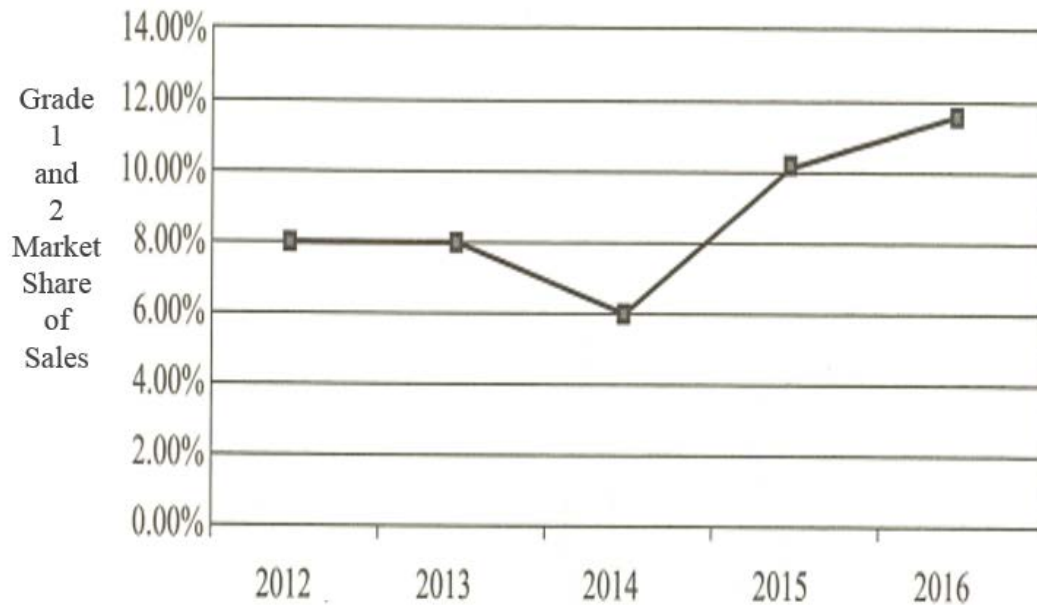


Figure 10. 2012-2016 Change in Fixed-Speed Multi-Split AC Energy Efficient (Grades 1 and 2) Share of Sales

Source: adapted from Cheng, 2017

For variable-speed and digital scroll multi-split AC units, the opposite is true for AC sales where all of the products sold in the Chinese market from 2015 to 2016 are already energy efficient products, with the vast majority qualifying as Grade 1 products as seen in Figure 10 and Figure 12. In fact, there is very little change in the efficiency distribution of products sold, with only a very slight decrease in the share of Grade 2 products between 2015 and 2016. This indicates that based on the 2008 energy efficiency labeling thresholds for multi-split ACs, the market is already fully saturated with Grade 1 products and that these existing efficiency thresholds are no longer effective in differentiating between the different efficiencies of products sold on the market. This also indicates that the existing thresholds for the designated “efficient” Grades 1 and 2 may be too low, as nearly all of the products sold have already exceeded or met these efficiency requirements and the model-weighted average efficiency shown previously in Table 4 are much higher with IPLV values in the range of 7 – 8 W/W.

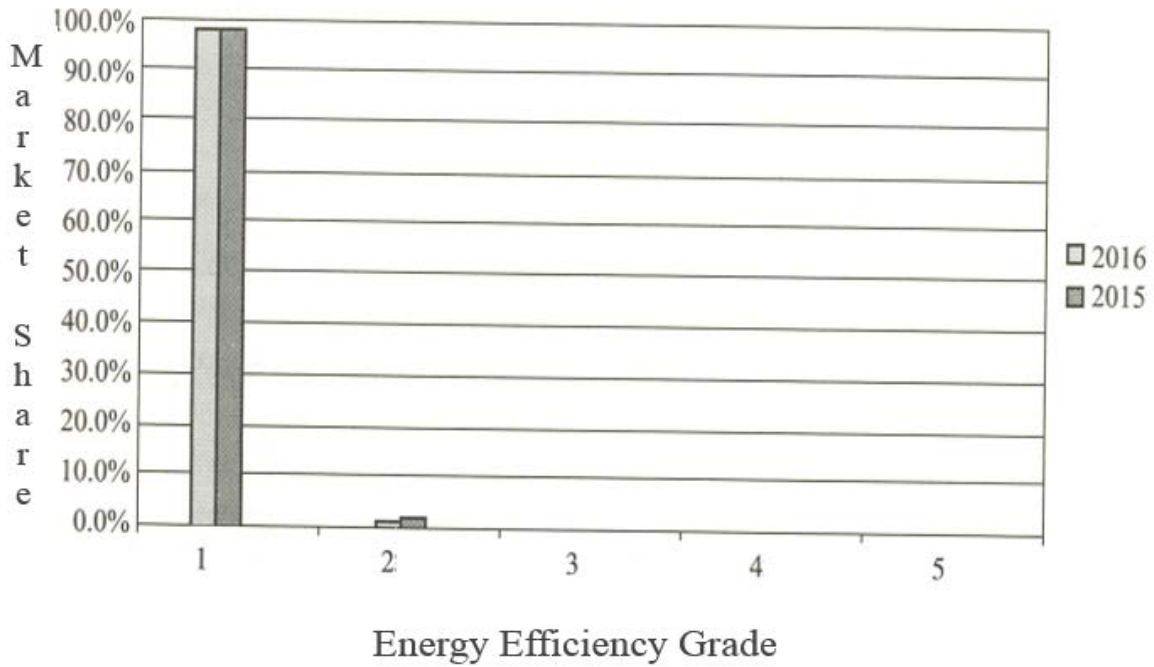


Figure 11. 2015 and 2016 Variable-speed Multi-split AC Sales Distribution by Energy Efficiency Grade

Source: adapted from Cheng, 2017

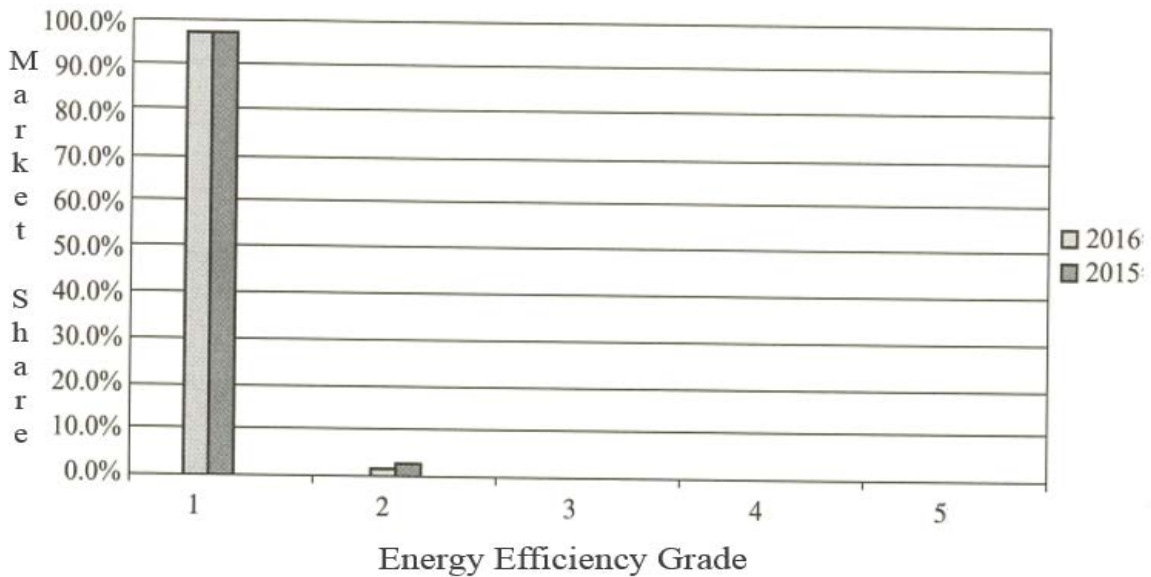


Figure 12. 2015 and 2016 Digital Scroll Multi-split AC Sales Distribution by Energy Efficiency Grade

Source: adapted from Cheng, 2017

4.3 Market Distribution by Price

Market distribution by price data was not readily available in the market survey reports we found. Completing this section will require either inputs from the in-the-field market survey being conducted by CNIS in support of the VRF MEPS revision, and/or sample survey of online retailers

with input by manufacturer on the most common models being sold.

4.4 Manufacturing Industry Overview

In terms of the landscape for manufacturers, the multi-split AC market has historically been dominated by major Japanese brands including Daikin, Hitachi, Mitsubishi Electric, and Toshiba, which had the largest market presence. Japanese brands continue to show robust performance in the market, with Daikin, Hitachi, Toshiba, Mitsubishi Heavy Industries, Mitsubishi Electric, Mitsubishi Heavy Industries Haier, Fujitsu, and Panasonic all showing steady growth with continuously expanding markets. Among them, Hitachi, Toshiba, Mitsubishi Heavy Industries Haier and others have achieved explosive growth in the retail market and are leading along with the dominant leader, Daikin (MEI, 2018).

Over the last few years, however, Japanese brands are facing growing competition from domestic Chinese manufacturers including Gree, Midea, and Haier. American brands including Johnson Controls, Carrier, Trane, York and McQuay and European brands such as Dunham-bush and Bosch are also entering China's VRF retail market by recruiting distributors and setting up retail stores but still faces barriers in terms of brand recognition (Chu, 2016, MEI, 2018). As a result, their individual market shares of total AC model products by these brands remain very small at under 2% as seen in Figure 13.

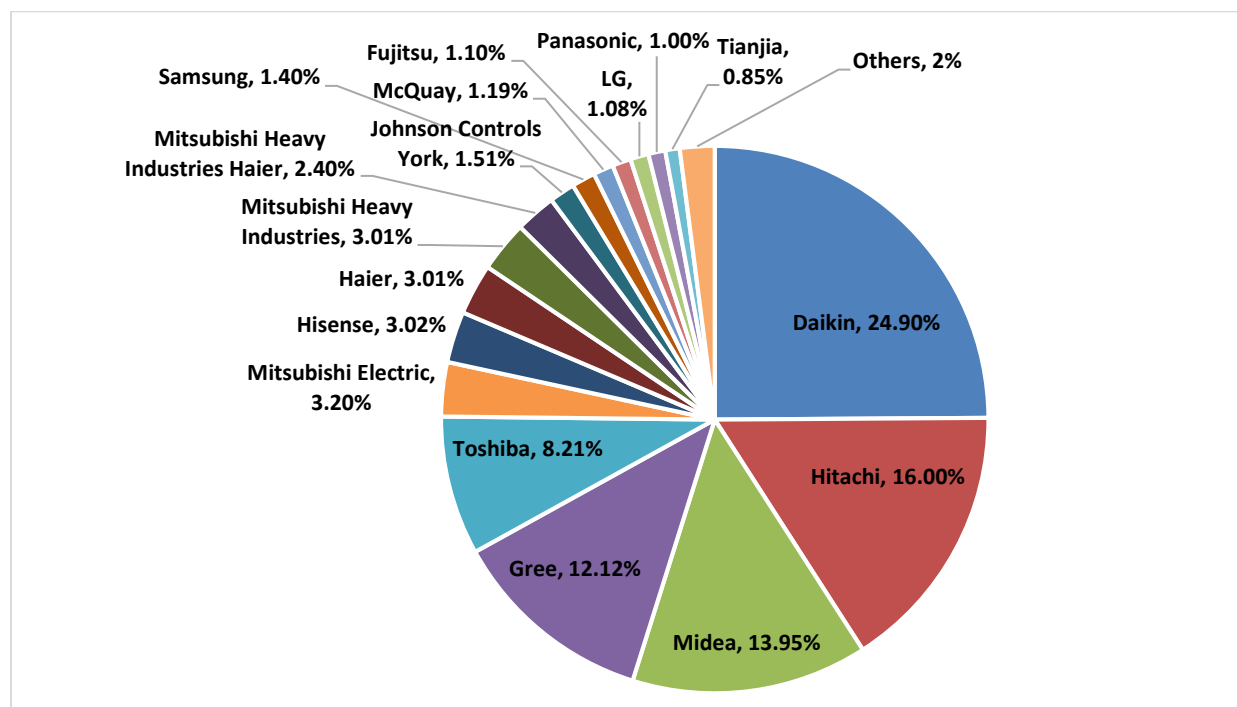


Figure 13. Chinese 2017 Multi-split AC Model Shares by Major Manufacturers

More specifically, Midea, Gree and Haier are the leading domestic Chinese brands. In 2017, their development is extremely rapid, having gained a combined market share of nearly 30%. In addition, other domestic brands such as Hisense and Tianjia have also emerged in the Chinese VRF market and achieved relatively fast growth in 2017. In addition, Korean brands, such as Samsung and LG have achieved rapid development in the Chinese VRF market and are steadily increasing their market shares.

In summary, the traditional VRF manufacturing landscape in China has not changed significantly, although the historically Japanese manufacturing leaders are facing increasing competition in the market. Strong Japanese brands have formed a deep-rooted retail channel base and continue to exert strong market influence. This is followed by rapidly expanding domestic Chinese brands, particularly Midea and Gree, followed by Korean, European and American brands.

5. Assessment of the Global Market

5.1 Global Market Trends

Driven largely in part by the Chinese market, global VRF sales have also been rising steadily since 2012 as seen in Figure 14.

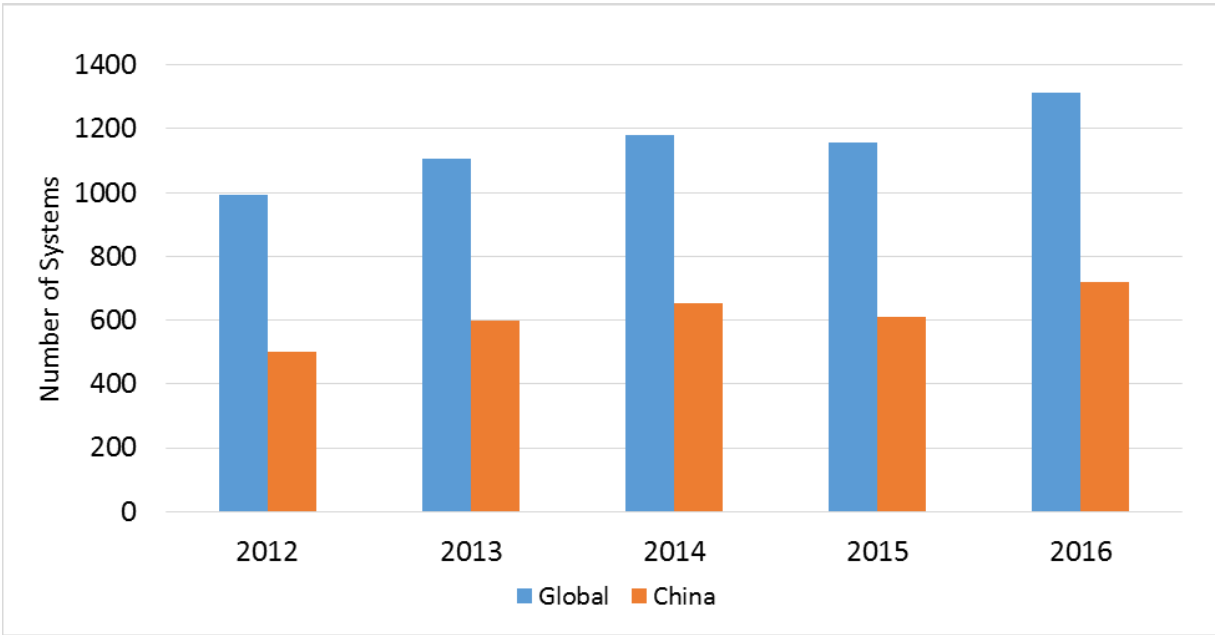


Figure 14. Comparison of Global and Chinese VRF Sales from 2012– 2016, in thousands
Source: JRAIA (2016)

In 2016, China accounted for the majority of global VRF sales with 54% share, followed by Europe, Japan, and South Korea, each with shares of around 10% (Figure 15). The leading global manufacturers are similar as the major market players in China, including Daikin with about 30% market share, Hitachi, Toshiba, Mitsubishi Electric, Midea, Gree, Haier, Samsung, and LG.

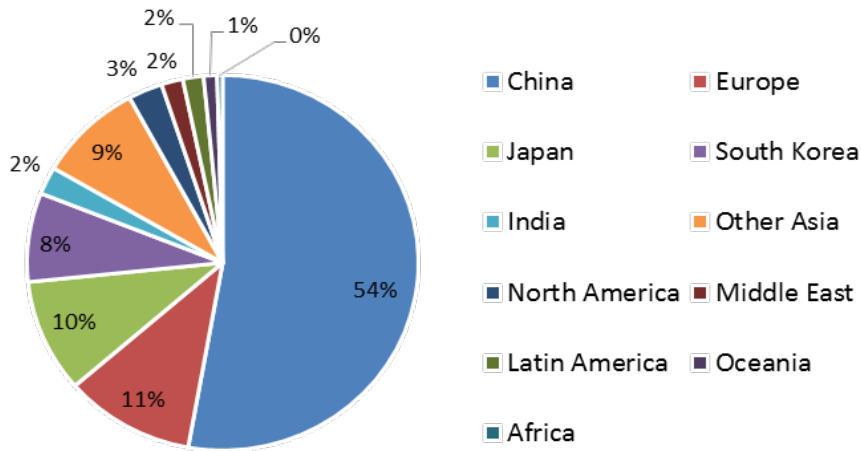


Figure 15. Global VRF Sales Market Share by Region in 2016

Source: JRAIA, 2016

China is also becoming a major global exporter of commercial multi-split ACs, including VRFs. Figure 16 shows China's rising export value for commercial multi-split ACs since 2016, with strong exports on a monthly basis throughout the year. Compared to the domestic market value, however, exports are still relatively small with less than 10% of the domestic market value. This again highlights China's dominance as a key consumer of commercial AC products, especially VRF systems, in the global market.

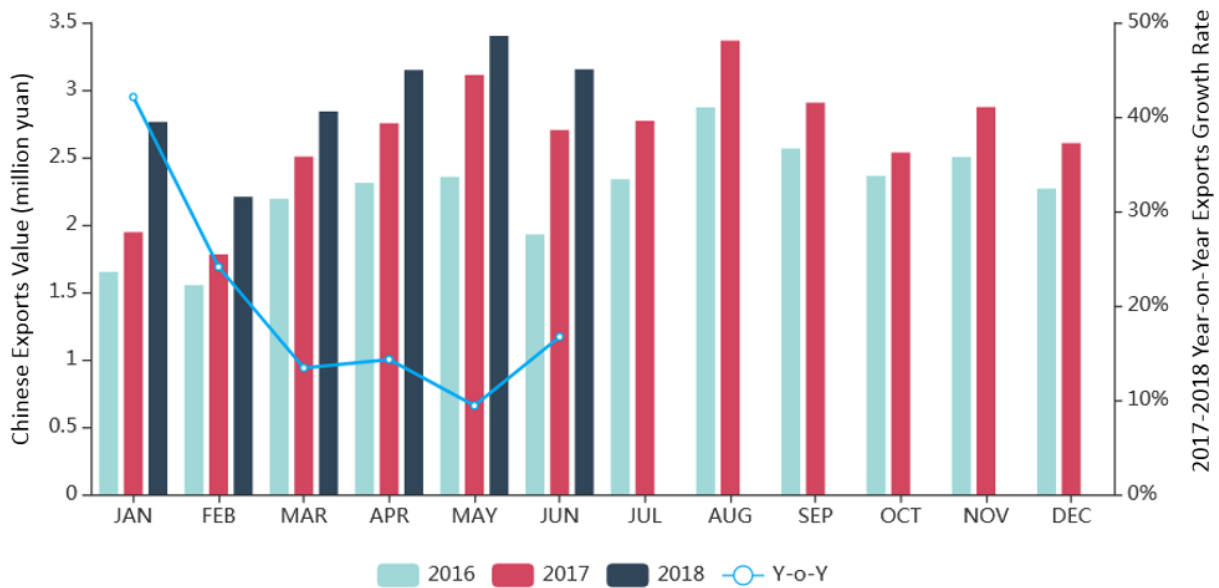


Figure 16. China's Commercial Multi-Split AC Exports by Month, 2016 - 2018

Source: ChinaIOL.com, 2018

5.3 Emerging Technology Trends

5.3.1 Efficiency Improvement

Over the past years, there have been important advancements in VRF technology and components, including in:

- Advancement in inverter-driven variable speed compressors.
- Direct driven fans to variable frequency drive, inverter-driven fans
- Better heat exchanger surfaces with multi-segmented coils
- Improved controls and diagnostics
- Better refrigerant charge and oil management

The highest-efficiency VRF systems in the U.S. market are provided by global manufacturers including Samsung, Mitsubishi Electric and Daikin as seen in Table 6. For VRF systems in the 20 to 28 kW cooling capacity range, the most efficient ductless VRF systems certified in the AHRI database have achieved IEER of over 9 W/W and EER of over 4 W/W.

Table 6. Most Efficient Certified Ductless VRF Systems by Product Category in U.S. Air Conditioning, Heating and Refrigeration Institute Database

	Manufacturer	Cooling Capacity (kW)	IEER* (W/W)	EER (W/W)
Heat Pump Air-cooled	Samsung	20	9.8	4.2
Heat Pump Water-cooled	Mitsubishi Electric	27	8.9	5.7
Heat Recovery Air-cooled	Samsung	20	9.8	4.2
Heat Recovery Water-cooled	Daikin	27	9.0	NA

Source: selected from ~2,800 models in U.S. AHRI Database, 2017

*Note: IEER is not directly comparable to IPLV, as it builds upon IPLV as a measure that expresses cooling part-load EER efficiency on the basis of weighted operation at various load capacities.

Mitsubishi has also introduced the first hybrid VRF system that provides simultaneous heating and cooling with heat recovery (Mitsubishi, 2018). This hybrid system uses refrigerant between the outdoor unit and hybrid branch controller, and water between the hybrid branch controller and the indoor units. It also requires a change in product configuration that will change the product category, efficiency metric and test procedures from traditional variable-speed or fixed-speed multi-split units.

5.3.2 Refrigerant Choice and Alternative Low-GWP Refrigerants

In China, 74% of packaged ACs outside of VRFs still use HCFC-based refrigerants while globally, the HCFC share of refrigerant use vary from 0% in North America, Japan, and Oceania to 42% in Other

Asia and 60% in the Middle East. Unlike other commercial packaged AC systems that still use a mix of HFC and HCFC refrigerants, VRFs already use 100% HFC-based refrigerants globally as seen in Table 7. For VRFs, the key low-GWP alternative refrigerant to replace R410A is R32.

Table 7. 2017 Refrigerant Shares for Commercial Packaged and VRF AC Systems by Region

	Non-VRF Packaged AC				VRF			
	Inverter Ratio (%)	Refrigerant Shares (%)			Inverter Ratio (%)	Refrigerant Shares (%)		
		HFC	HCFC	Other		HFC	HCFC	Other
China	20%	26%	74%	0%	100%	100%	0%	0%
Japan	99%	100%	0%	0%	100%	100%	0%	0%
Other Asia	26%	58%	42%	0%	96%	100%	0%	0%
Middle East	10%	40%	60%	0%	100%	100%	0%	0%
Europe	91%	100%	0%	0%	100%	100%	0%	0%
North America	2%	99%	0%	1%	100%	100%	0%	0%
Oceania	99%	100%	0%	0%	100%	100%	0%	0%

Source: JRAIA, 2018

Drop-in tests of Daikin VRF systems replacing R410A VRFs with R32 has shown 9.5% improvement in IEER with improved heating and cooling capacities, but higher discharge temperatures (Tsuji and Imada, 2013). Theoretical analysis have also shown improved COP of 5% for heating and 6% for cooling mode with the refrigerant replacement of R32 for R410A (Yildirim et al. 2017).

In May 2018, Mitsubishi Electric launched its first R32-based large-scale multi-hybrid VRF system for the United Kingdom market. Similar to the hybrid VRF system discussed earlier, this R32-based model also features a two-pipe heating and cooling system with a hybrid branch controller (Air Centric, 2018). This hybrid configuration and the use of R32 enables smaller charge sizes that helps reduce flammability risks for mildly flammable alternative refrigerants.

R32 is considered mildly flammable but safe with an A2L safety classification under ASHRAE Standard 34-2013's refrigerant safety classes. The Japan Society of Refrigeration and Air Conditioning Engineers have conducted risk assessment studies of mildly flammable refrigerants, including a comprehensive risk assessment of R32 use in VRF systems (JSRAE, 2015). Their findings on the probability of fire ignition are shown in Table 8 below, and indicates worst case scenarios for both indoor and outdoor operation where the fire ignition probability exceeded allowable levels.

Table 8. Probability of Fire Accident for R32 VRF System under Specified Indoor and Outdoor Operation Cases

In each installation cases				[time/(unit*year)]	Not allowable	Allowable	
Installation case				Fire accident probability A			
Site	Type	Constituent ratio P	Allowable probability	Without measures		With measures	
				No vent	Vented		
Indoor	Karaoke	Ceiling	2.1E-03	1.0E-09	1.8E-07	4.4E-11	0.0E+00
	Restaurant	Floor	2.0E-02		3.8E-07	5.4E-09 ^{*1)}	2.6E-10 ^{*2)}
	Hair salon	Ceiling	1.6E-03		1.3E-09	1.2E-10	6.8E-12
	BBQ restaurant	Ceiling	7.8E-04		2.8E-09	4.4E-10	1.5E-11
	Ceiling space	Ceiling concealed	1.0E-00		3.0E-10	-	3.0E-11

Ventilation turned off at night

Installation case				Fire accident probability A			
Site	Type	Constituent ratio P	Allowable probability	Without measures		With measures	
				No vent	Vented		
Indoor	Office	Ceiling	3.8E-01	1.0E-09	7.6E-09 ^{*3)}	3.5E-12	3.5E-12

Total in market

Total = Σ(P * A)	4.0E-01	1.0E-09	1.1E-08	1.1E-10	3.7E-11
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- *1) Supply and exhaust on the ceiling surface cannot dilute refrigerant gas leaked from floor unit.
- *2) Measures are mechanical ventilation with a vent opening near the floor, or , agitation by the indoor fan.
- *3) Ventilation turned off 18:00 to 09:00. Ignition sources are smoking by overtime people and water heater driving after people left from office.

In each installation cases				[time/(unit*year)]	Not allowable	Allowable
Installation case				Fire accident probability A		
Site	Constituent ratio P	Allowable probability		Without measures		With measures
				No vent	Vented	
Out-door	Usual	9.4E-01	4.0E-09	1.9E-11	—	—
	Each floor	5.0E-02		3.0E-09	—	—
	Semi-underground	1.0E-04		1.1E-07	—	2.5E-13 ^{*1)}
	Machinery room	6.0E-03		6.1E-08	—	3.2E-09 ^{*2)}

Total in market

Total = Σ(P * A)	1.0E+00	4.0E-09	5.4E-10	—	1.9E-11
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- *1) Mechanical ventilation with suction duct
- *2) Mechanical ventilation, 2times/h*2system

Source: JSRAE, 2015

6. Conclusions

China is emerging as a key driver of the global market for multi-split cooling systems, particularly for variable speed multi-splits, and now accounts for more than half of global VRF sales. At the same time, Chinese manufacturers such as Haier, Gree and Midea are also emerging as larger

players in the multi-split AC manufacturing industry, particularly for the domestic Chinese market, where they now closely follow the traditionally strong Japanese manufacturers in terms of market shares. All of these trends suggest that there is significant opportunity to capture energy savings and both direct (i.e. through energy use) and indirect (i.e. through refrigerant choice) greenhouse gas emissions emitted through the use of multi-split cooling systems. The upcoming revision of China's 2008 MEPS for multi-split AC systems is one such opportunity.

Both model-weighted and sales-weighted market data from recent market surveys show that the average energy efficiency of fixed-speed, variable-speed and digital scroll multi-split air conditioning systems in the Chinese market have far surpassed the 2008 MEPS levels. In terms of variable-speed multi-split models available on the market, both the minimum efficiency and model-weighted average efficiency levels of models across all capacity sizes already far surpassed the MEPS requirements, with minimum IPLV cooling values ranging from 3.5 to 6 W/W and average IPLV cooling values ranging from 7.3 to 8.2 W/W. While some of these models may only be prototype models that are registered in the China Energy Label database and not yet available at a commercial scale and may differ from the market average baseline model in terms of number of indoor units, there is a general trend of increasing efficiency across all capacity classes. For both variable-speed and digital scroll units, the vast majority of units sold have also already reached efficiency Grade 1 (most efficient) products with IPLV cooling values of around 3.6 W/W, compared to MEPS IPLV cooling values of 2.7 to 2.8 W/W (depending on capacity size). For fixed speed units, there is still a wide distribution of efficiency grades being sold, with clustering of sales mostly in efficiency Grades 3 and 4, and sales-weighted average efficiency of 3.3 W/W for IPLV cooling value in 2016. The trend over the last few years reflect the slow improvement towards more efficient fixed-speed units, but average efficiency levels have nevertheless surpassed the 2008 MEPS level with greater technical potential for improvement remaining.

Globally, the most efficient units on the U.S. market and the emergence of new technologies such as Mitsubishi's hybrid VRF system demonstrate that there is still significant room for technical efficiency improvement. The introduction of new VRF configurations such as the hybrid system will also require more research to understand and develop new efficiency metrics and test procedures for this new product category. At the same time, research addressing possible safety concerns of R32, a mildly flammable low-GWP alternative to the current R410 refrigerant used in VRF systems, as well as commercial development of the first R32-based hybrid VRF system, underscore the existence of low-GWP alternative refrigerants that can be considered in China's new MEPS and energy labeling revisions.

Therefore we conclude that:

- Demand for multi-splits is growing rapidly not only within China as a result of strong economic growth and commercial building (as well as some residential) demand for cooling services, but is also driving global VRF sales.
- Domestically, Chinese manufacturers are emerging as new players in the multi-split AC manufacturing industry.
- Market survey data show that the average energy efficiency of all three types of multi-split AC systems have far surpassed the existing 2008 MEPS efficiency requirements, suggesting that more stringent requirements are needed to reflect rapidly changing market conditions.
- Improving the stringency of multi-split AC MEPS in China will bring significant economic, energy and emissions benefits to China and globally as the Chinese multi-split market

continues to expand.

- Including specifications on the configuration and number of indoor units in the test method will help address possible variations in energy use from the varying number of indoor units between different product models

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