R290 Split Air Conditioners Resource Guide

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Table of Abbreviations

A	AC	Air Conditioning
	ACR&HP	Air Conditioning, Refrigeration & Heat Pump
	ACs	Air Conditioners
	AHRI	Air Conditioning, Heating and Refrigeration Institute
	AL	Aluminium
	ANSI	Approved American National Standard
B	BAU	Business as Usual
	BEE	Indian Bureau of Energy Efficiency
	BMU	Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
	BTU	British Thermal Unit
C	C4	Cool Contributions Fighting Climate Change
	CC	Cooling Capacity
	CCC	China Compulsory Certification
	CEC	China Environmental United Certification Center
	CED	Cumulated Energy Demand
	CHEAA	China Household Electrical Appliances Association
	CO	Carbon Monoxide
	CO_2	Carbon Dioxide
	COP	Coefficient of Performance
	CSN	Complete Satisfaction Number
	CSPF	Cooling Seasonal Performance Factor
	CU	Copper
D	DMT	Deutsche Montan Technologie Gmbh
E	EC	Electronically Commutated
	EE	Energy Efficiency
	EER	Energy Efficiency Ratio
	EEV	Electronic Expansion Valve
	EIA	Environmental Investigation Agency
	EN	European Norm
	EOL	End-Of-Life
	EPA	Environmental Protection Agency in Ghana
	EU	European Union
F	FECO	Chinese Foreign Economic Cooperation Office
G	GCI	Green Cooling Initiative
	GHG	Greenhouse Gas
	GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
	GWP	Global Warming Potential
H	H_2O	Water
	HC	Hydrocarbon
	HCl	Hydrochloric Acid
	HCFCs	Hydrochloro-fluorocarbons
	HF	Hydrofluoric Acid
	HFCs	Hydrofluorocarbons
	HFO	Hydrofluro-olefin
	HP	Horse Power | Heat Pump
	HPMP HCFC	Phase-Out Management Plan
	HPWH	Heat Pump Water Heater

I	IDU	Indoor Unit
	IEA	International Energy Agency
	IEC	International Electrotechnical Commission
	IKI	Internationale Klimaschutzinitiative (International Climate Initiative)
	IPCC	Intergovernmental Panel on Climate Change
	ISEER	Indian Seasonal Energy Efficiency Ratio
	ISO	International Organization for Standardization
J	JARN	Japan Air Conditioning, Heating & Refrigeration News, Ltd.
	JRAIA	Japan Refrigeration and Air Conditioning Industry Association
L	LCIA	Lifecycle Impact Assessment
	LFL	Lower Flammability Limit
	LPG	Liquefied Petroleum Gas
M	MEPS	Minimum Energy Performance Standards
	MIT	Mitigation
N	NAMA	Nationally Appropriate Mitigation Actions
	NC	National Committee
	NDCs	Nationally Determined Contributions
	NOU	National Ozone Unit
O	ODP	Ozone Depleting Potential
	ODS	Ozone Depleting Substance
	ODU	Outdoor Unit
Q	QCR	Qualification, Certification and Registration
R	RAC	Refrigeration And Air Conditioning
S	SC	Sub Committee
	SCOP	Seasonal Coefficient Of Performance
	SEER	Seasonal Energy Efficiency Ratio
	Split ACs	Split-Type Air Conditioning Systems
T	TC	Technical Committee
	TEAP	Technology And Economic Assessment Panel
	TESDA	Philippines' Technical Education And Skills Development Authority
	TEV	Thermal Expansion Valve
	TFA	Trifluoro Acetic Acid
	ToT	Training of Trainers
U	U4E	United For Efficiency
	UBA	Umweltbundesamt (German Environment Agency)
	UFL	Upper Flammability Limit
	UNEP	United Nations Environmental Program
	UNFCCC	United Nations Framework Convention On Climate Change
	UNIDO	United Nations Industrial Development Organization
W	WG	Working Group

Foreword

Room air conditioning appliances become more and more popular worldwide. 129 million units have been sold in 2017 (JARN, 2018), including roughly 100 million single-split *air conditioners* (ACs). Compared to the year 2007, this means a growth in sales of such appliances by 64% - in only ten years. The reasons for this trend are a growing world population, a rising middle class in countries with emerging markets and, more recently, rising temperatures due to climate change.

Ironically, the latter is caused to a considerable share by air conditioning itself through the energy consumption associated with the use of air conditioning equipment. The *International Energy Agency* provides in a current report (IEA, 2018) that 20% of the energy consumption in buildings is due to air conditioning. Further, it projects that energy consumption in this field will more than triple by the year 2050. This trend is driven mainly by the residential sector where single-split AC appliances are the dominating type of AC equipment. Accelerated energy efficiency levels for these type of appliances in the short term are crucial to minimize or even decrease the currently growing impact on the climate.

The significant climate impact of room ACs is not only made by fossil fuel-based electricity supply, but also a result of the predominant and massively growing use of halogenated refrigerants such as R22, R410A, and, to a growing extent, R32 with high *global warming potential* (GWP), which today have a significant share of the overall greenhouse gas emissions caused by air conditioners. For single-split room ACs, the loss of the initial refrigerant charge over the lifetime is 100% or even more, caused through leakages during operation as well as during installation and disposal at the end of life. Therefore, the use of natural refrigerants with very low GWP not only can result in superior energy performance, but also lead to negligible GHG emissions through refrigerant losses during service and at the end of life.

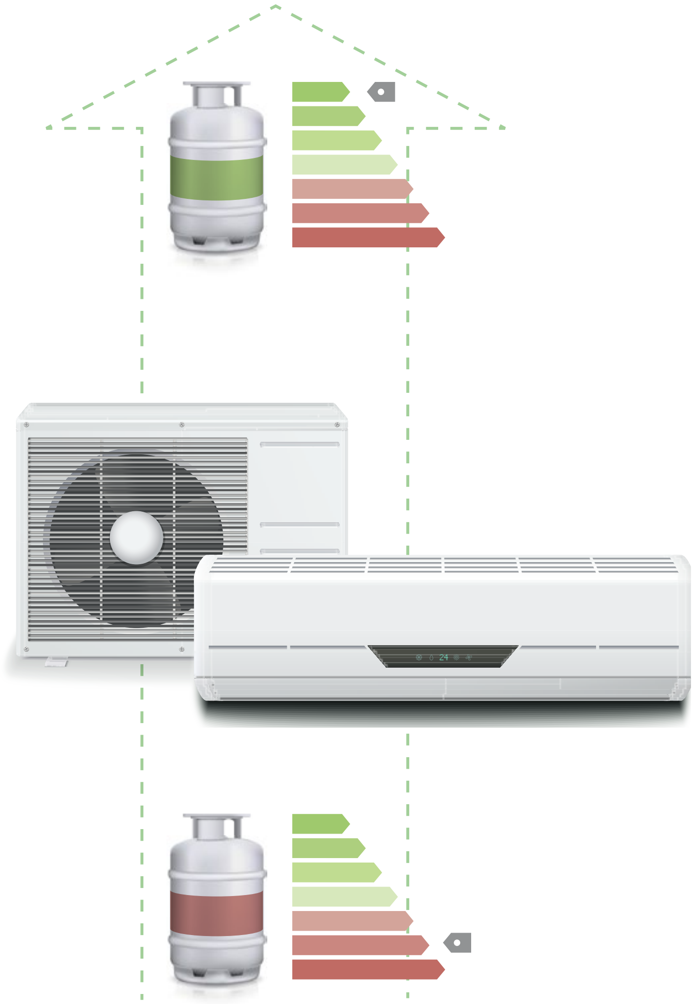
This guide clearly shows that single-split room ACs equipped with R290 (propane) exhibit significant environmental advantages through good energy performance and a GWP close to zero. The guide shall contribute to addressing and demystifying all aspects relevant for the successful introduction of R290 split Air Conditioners.

A good example that proofs the viability of this option comes from India where a domestic manufacturer offers a single-split air conditioner with R290 refrigerant. The product is the most energy-efficient appliance of this product group on the Indian market. More than 600,000 units have been sold to end users so far with no reported incidents because they are safely installed by qualified and certified personnel. This example should encourage other governments and manufacturers to introduce their R290 solutions to the domestic and worldwide market. Considering the phase-down of hydrofluorocarbons such as R410A and R32 according the recent Kigali Amendment to the Montreal Protocol, which already started with the first step of -10% of the baseline, R290 is today the only viable and future-proof choice for residential and light commercial single-split air conditioning.

Dr Bettina Rechenberg
Director General of Division III – Sustainable Production and Products, Waste Management
German Environment Agency

Purpose of this guide

Split-type air conditioning systems (split ACs) are currently the most commonly used appliance for space cooling worldwide. In many regions split ACs operate with moderate energy efficiency levels and use refrigerants that are highly damaging to the climate. Large amounts of fossil fuel-based electricity is consumed and leaking *hydrochlorofluorocarbon* (HCFC) and *hydrofluorocarbon* (HFC) refrigerants often make them account for a substantial proportion of *greenhouse gas* (GHG) emissions in the refrigeration, *air conditioning and heat pump* (RACHP) sectors in developing countries. This could become more significant as the worldwide demand for split ACs is growing at a rapid pace driven by increasing population, rising middle class and urbanisation.



According to IEA (2018) estimates, space cooling accounted for around 10% of total electricity demand worldwide in 2016, whilst in 2023 UNEP (2023) estimates that already 20% of global electricity demand is required for cooling. This illustrates the rapid growth in ACs. Under a business as usual scenario, the energy demand from air conditioners will more than triple by 2050. The increase in absolute numbers of split ACs will be the most significant of all, escalating from just over 850 million to over 3.7 billion.

Market assessments that GIZ carried out in numerous countries show that accelerating the transition to more energy-efficient split ACs that use the natural refrigerant R290 (propane) can play a key role in creating a more sustainable RACHP sector. Leapfrogging to high efficiency appliances using R290 reduces the energy consumption and GHG emissions and thus provides a significant opportunity to contribute to national climate action plans, *Nationally Determined Contributions* (NDCs). *Figure 1* and *2* on *page 8* sketches different mitigation scenarios for the market uptake of energy-efficient R290 split AC units and depicts the total and direct GHG emission reduction potential until 2050. A market share of 50% until 2050 may cut down total GHG emission by 25% by 2050[1].

While there is an urgent need for action in the sector, there are several barriers to a market transition, such as safety concerns about the flammability of R290, lacking awareness and uncertainties about new technologies, as well as limited understanding of the proper treatment of the refrigerants in the processes of manufacturing, installing, operating, and disposing of appliances. There is often a hesitance to invest in such technology, despite significant reduction potential in energy costs.

1 Assumptions are based on studies by HEAT GmbH and GIZ. The trend of the curves show that the market uptake of R290 split ACs will achieve significant reductions in GHG emissions after 2025 when old inefficient appliances reach their end-of life and the total share of R290 split ACs in the overall stock increases to significant numbers.

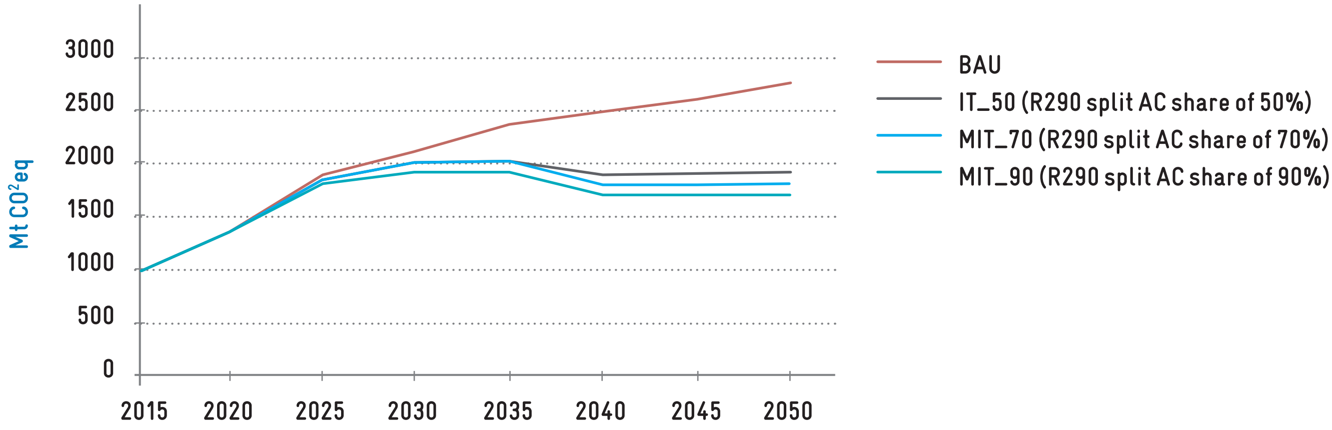


Figure 1: Total GHG emissions due to the use of split ACs (2015-2050)

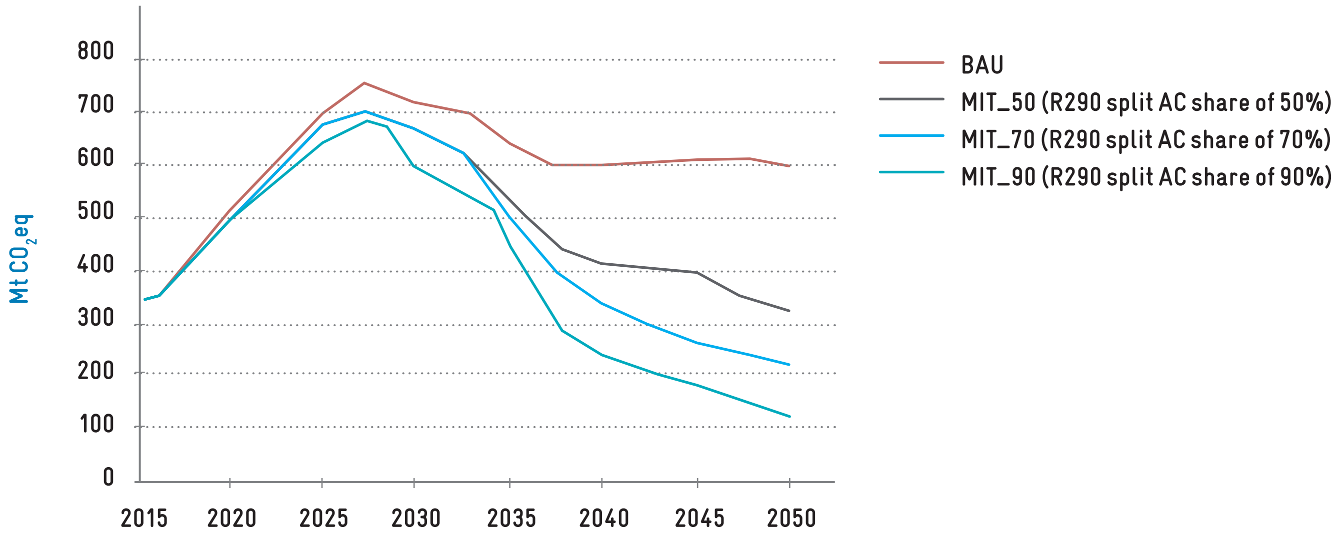


Figure 2: Total direct GHG emissions due to the refrigerant leakage of split ACs (2015-2050)

The objective of this resource guide is to inform stakeholders about the factors that are deemed crucial for a successful market transition to energy-efficient R290 split ACs. The guide addresses:

Political decision makers who are confronted with energy efficiency and refrigerant policy making, and who would like to improve their understanding about R290 split ACs in order to take informed consultations with the industry and other relevant bodies.

National standardisation, custom and certification bodies that are tasked with the development and issuance of standards on performance testing, product safety and technician skills required for R290 split ACs.

The **split AC industry**, including manufacturers, assemblers, contractors and installation companies, which are considering to transition or expand their business to manufacture, sales, and servicing of R290 split ACs.

This guideline intends to address knowledge gaps as well as the concerns that hinder the introduction and application of R290 split AC. This guide tackles all topics relevant to R290 split AC and provides a set of references for more detailed information at the end of each chapter.

The information in this guide is built on practical experience gained in GIZ Proklima projects (including IKI projects like the conversion of Godrej & Boyce production line to R290 split AC in India, Cool Contributions fighting Climate Change, Green Chillers NAMA project Indonesia, Green Cooling Initiative) and interviews with industry players. The guideline is intended to enable key stakeholders to take effective and coordinated measures to introduce Green AC technology in their country. Ultimately, it aims to encourage policy makers to facilitate the market uptake of energy-efficient split ACs using R290.

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1. Technical design and components of split AC

Demand for space cooling is growing rapidly due to rising middle classes, urbanisation and climate change. Split ACs already dominate the market share of space cooling appliances in many markets and are projected to increase significantly in the next decades.

The most popular split-type air conditioning systems are single-split ACs, also known as mini-splits. The single-split AC consists of two modules that are connected by refrigerant piping and electrical cables:

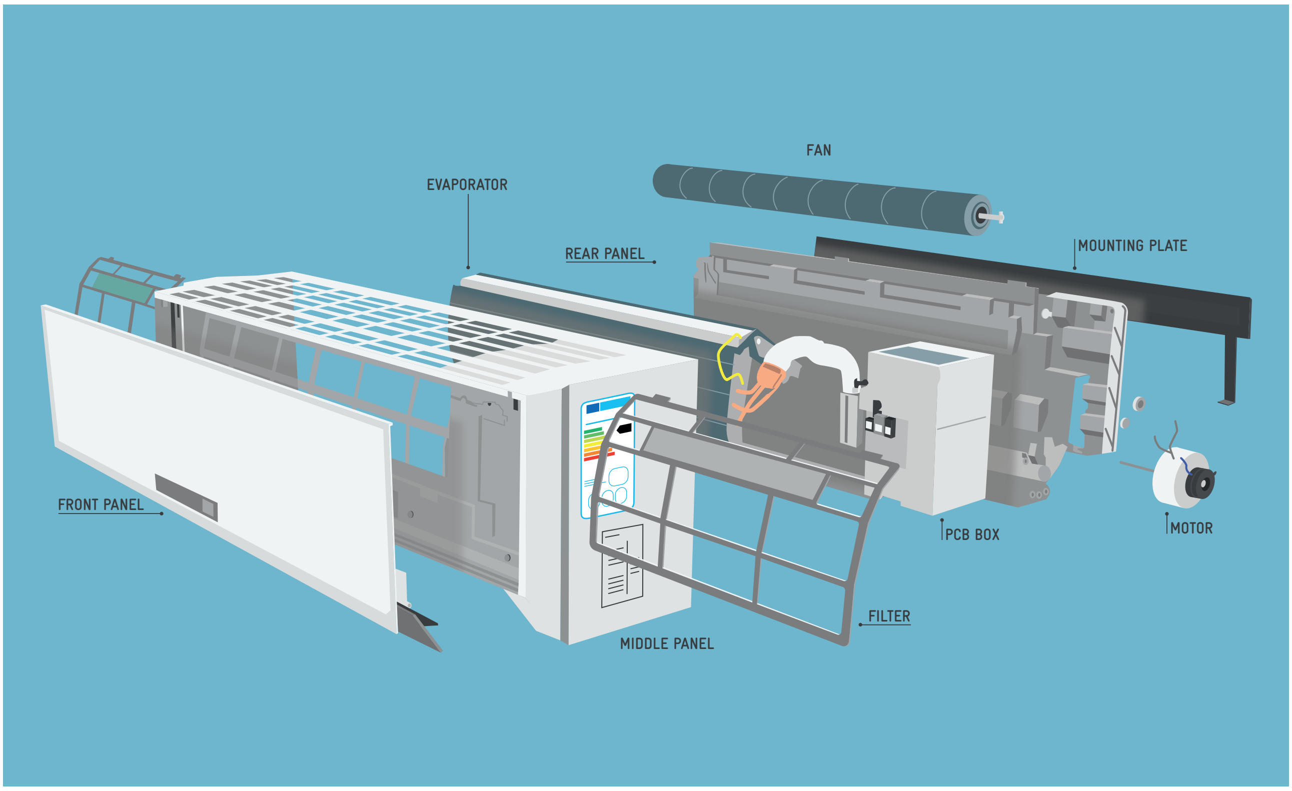


Figure 3: Main components of IDU

- *An indoor unit* (IDU) including the evaporator (when in cooling mode) and a fan that is mounted inside the air-conditioned room (*Figure 3*).
- *An outdoor unit* (ODU) containing the compressor, condenser (when in cooling mode), fan, and expansion device which is installed outside (*Figure 4*).

Worldwide, split ACs are mostly used for cooling purposes only and therefore usually cooling-only or non-reversible systems. In more moderate climates, split AC technology is offered with reversible mode, which provides both cooling and heating in one system. This guide focuses on the cooling-only models. In addition to single-split AC systems, the market offers multi-split AC systems comprising one ODU linked to several IDUs. Multi-split systems may be suitable for space cooling (or heating) of multiple rooms or large rooms. This guide focuses on single-split units because they are the most commonly used system for residential customers and are also widely employed in office spaces and commercial areas such as hotels and supermarkets. The relatively low investment, simple installation, and low space requirement are main advantages of single-split ACs.

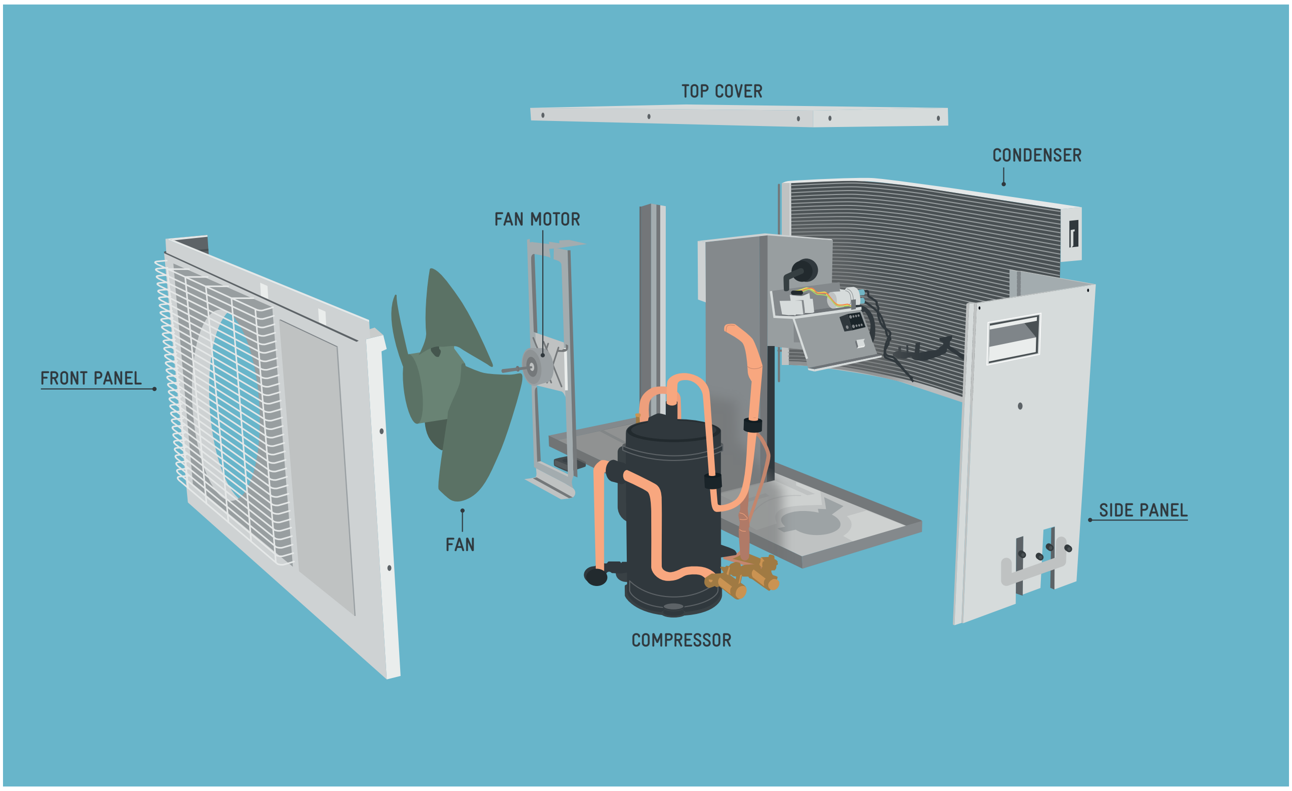


Figure 4: Main components of ODU

The available cooling capacity classes for single-split ACs range roughly from 1.8 to 7 kW (6,000 to 24,000 Btu/h), although some products exceed this range. The suitable cooling capacity is defined by the cooling demand of the space that the split AC is intended to be installed within. This usually takes into account room size and location, local heat sources and the number and behaviour of end-users. The cooling capacity classes are expressed in different units depending on the applicable country or region. The most common classes are listed in *Table 1*:

Common Cooling Capacity Classes				
1.76 kW	2.64 kW	3.52 kW	5.28 kW	7.03 kW
6.000 Btu/h	9,000 Btu/h	12,000 Btu/h	18,000 Btu/h	24,000 Btu/h
0.5 RT[2]	0.75 RT	1 RT	1.5 RT	2 RT

Table 1: Overview of most common cooling capacity classes for single-split ACs, expressed in different units

2 RT: Refrigeration ton (or ton of refrigeration), 1 RT equals 12,000 British thermal units per hour (Btu/h) of refrigeration capacity

1.1. Working principle of room AC systems

The refrigeration technology is the common vapour compression refrigeration cycle as illustrated in *Figure 5*. It comprises four main components: evaporator, compressor, condenser and an expansion device, along with various ancillary components for various purposes including controlling and optimising operation as well as for maintenance and reliability.

The refrigeration cycle contains liquid refrigerant at high pressure in the liquid line passing through an expansion device (restrictor), which typically could be a capillary tube or an expansion valve. Here the refrigerant pressure is reduced abruptly causing a part of the liquid to immediately vaporize. This effect lowers the temperature of the liquid-vapour refrigerant to below the temperature of the (indoor) surroundings. The cold refrigerant is then routed through the injection line into the evaporator, which is within the IDU. The liquid part of the refrigerant begins to evaporate by absorbing heat from the surroundings, transferred through the exchanger fins and tubes, from the air. The circulating room air that has been passed over the evaporator is cooled accordingly. Once the refrigerant has been fully vaporised, it is drawn through the suction line into the compressor. The compressor compresses the vapour and thus raises the pressure to a value corresponding to a saturated vapour temperature that lies above the temperature of the air surrounding the ODU. The high-pressure refrigerant vapour is now discharged into the condenser (which may be a finned tube or microchannel heat exchanger), where its heat is transferred through the condenser material to the surrounding air passing over the coil and is thereby condensed back into a liquid state. This heat that has been rejected to the surrounding ambient is approximately equal to that absorbed in the evaporator plus the electrical power consumed by the compressor. The high-pressure liquid refrigerant now flow from the bottom of the condenser tubes and into the liquid line, to complete the refrigeration cycle.

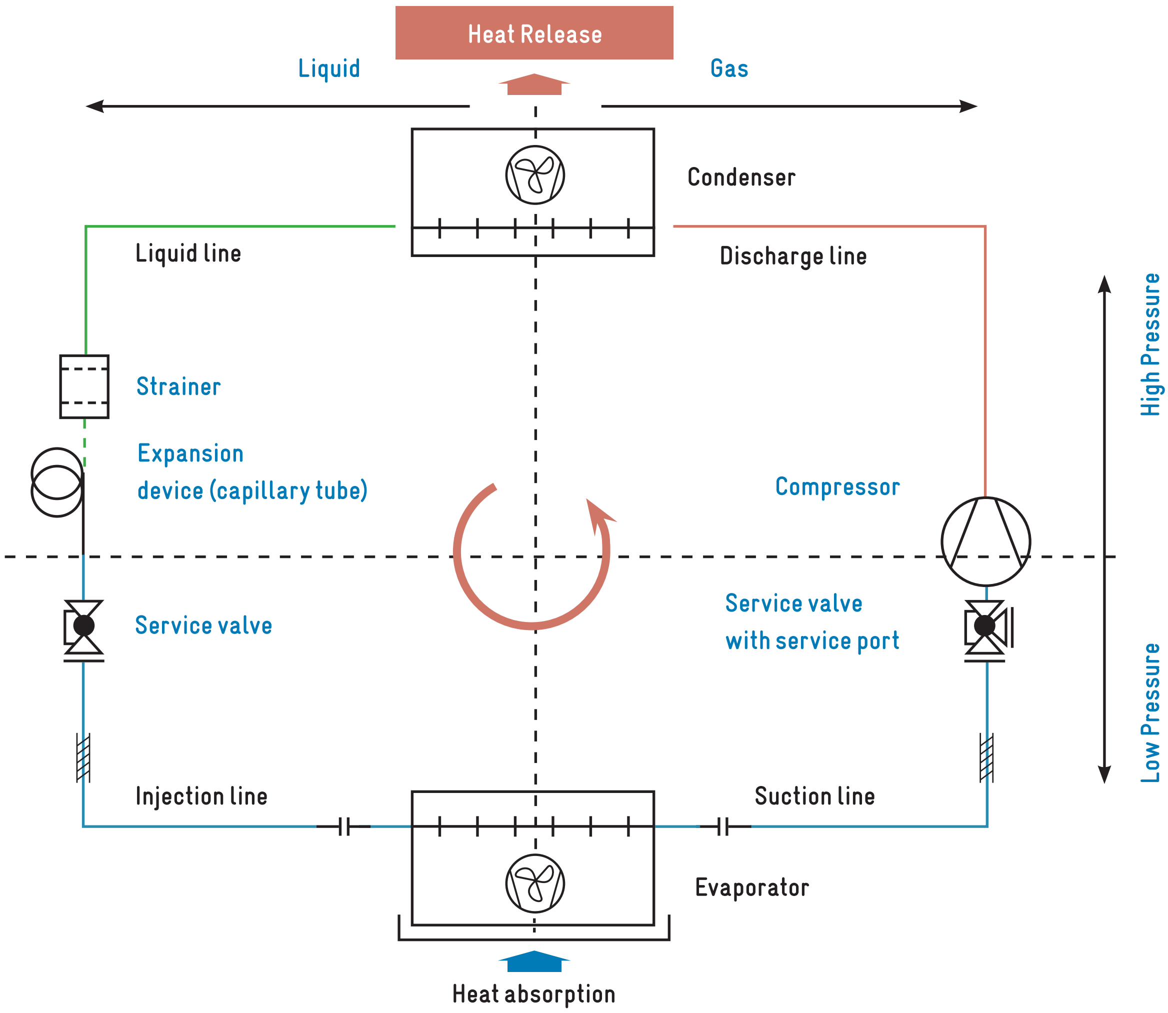


Figure 5: Basic split AC vapour compression cycle and key system components

1.2. Refrigerant characteristics

Currently, the most common refrigerants for split ACs are R22, R410A, and R32. The ozone-depleting R22 is subject to the ongoing international HCFC phase-out under the Montreal Protocol. Non-Article 5 (developed countries) countries have fully phased out HCFCs as refrigerant in new units and the phase-out in Article 5 countries (developing countries) will be completed by 2030. R22 is primarily replaced by the HFC mixture R410A (50% R32 and 50% R125) and R32. Both are HFCs with high *global warming potential* (GWP) and are subject to the HFC phase-down under the Kigali Amendment to the Montreal Protocol. The gradual reduction of HFCs to 10-20% of the baseline by the late 2040s has been agreed. On 1st of January 2019, the Kigali Amendment entered into force. The first reductions by non-Article 5 countries is due in 2019. Article 5 countries will follow with a freeze of HFC consumption levels in 2024 and for some countries in 2028.

Refrigerant		R22	R410A	R32	Low GWP HFC/ HFO blends	R290
Type		HCFC	HFC blend	HFC	HFC and/or HFO blend; e.g., R454A, R454B, R452B, etc.	HC
GWP (100 year)[3]		1,960	2,256	771	270 – 779	0.02
GWP (20 year)[4]		5,690	4,715	2690	942 – 2274	0.072
Production CO_2-eq impact		High	High	High	Very high	Low
Other environmental impacts (incl. from production)[5]		ODS, toxic metals, etc.	ODS, toxic metals, etc.	ODS, toxic metals, etc.	TFA, ODS, toxic metals, etc.	H^2O and CO_2
Thermal degradation products[5]		HF, HCl and CO_2	Carbonyl fluoride, HF and CO_2	Carbonyl fluoride, HF and CO_2	Carbonyl fluoride, HF and CO_2	H_2O and CO_2
Refrigerant Efficiency Indicators*		High	Low	High	Medium	High
Cost of refrigerant[6]		Low/Medium	Medium/High	Medium	High	Medium/Low
Subject to patent on:	· Substance · Production · Systems	· No · Yes · Yes	· Yes · No · Yes	· No · Yes · Yes	· Yes · Yes · (Probably)	· No · No · Yes
ISO 817 safety Classification		A1 – lower toxicity and non- flammable	A1 – lower toxicity and non-flammable	A2L – lower toxicity and lower flammability	A2L to A3 – lower toxicity and lower to higher flammability	A3 – lower toxicity and higher flammability
Training requirements		General safe handling of refrigerants; Responsible han- dling of ODS	General safe handling of refrigerants	General safe handling of refrig- erants; Training and certification of manufacture and service technicians on flammable refrigerants	General safe handling of refrig- erants; Training and certification of manufacture and service technicians on flammable refrigerants	General safe handling of refrig- erants; Training and certification of manufacture and service technicians on flammable refrigerants
Use restrictions/ implications		Subject to HCFC phase-out	Restricted use or ban in regions with GWP based HFC phase out regimes (e.g. EU F-Gas)	Restricted use or ban in regions with GWP based HFC phase out regimes (e.g. EU F-Gas)	Restricted use or ban in regions with GWP based HFC and HFO phase out regimes (e.g. EU F-Gas)	No ban

Table 2: Overview of refrigerants for split type ACs adapted from GIZ Proklima Input in U4E (2017)

3 Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, 2013

4 IPCC 6th Assessment report, AR6 (Chapter 7; Forster et al., 2021)

5 Survey of selected fluorinated GHGs, Danish Ministry of the Environment, 2014; and according to comments received by Prof. Dr. Andreas Konrath

6 While these are indicative of current costs, future costs of R290, R32 and low-GWP blends will depend significantly on the scale of production due to the Kigali Amendment to the Montreal Protocol, whilst R290 should be lower if sufficient scale is achieved.

* Such as theoretical cycle efficiency, compression ratio, fluid thermophysical properties, etc.

1.3. Energy efficiency performance

Compressor performance and size and effectiveness of heat exchangers largely determine the overall system energy efficiency of split ACs, so these components need to be targeted primarily to improve energy efficiency. Optimisation of the heat exchanger for condenser and evaporator can be achieved through increasing the surface area, optimal design of flow paths and the choice of material. For instance, use of:

- Optimised fin arrangements and circuit geometries
- Turbulators/extended internal tube surfaces
- Extruded aluminium micro-channels

These technologies aim to increase the amount of heat transferred per m^2 of exchanger area or per m^3 of exchanger volume, thereby reducing the approach temperature difference between air and refrigerant. With new, advanced manufacturing techniques, novel designs with improved exchanger effectiveness are increasingly feasible.

Introducing a variable-speed compressor can also lead to major energy savings, as the technology can adapt system cooling capacity to part loads even with modest changes in cooling demand. Unlike fixed speed AC compressor which operates in an on/off mode, the speed of the compressor motor changes in proportion to the difference between set-point temperature and the actual room temperature.

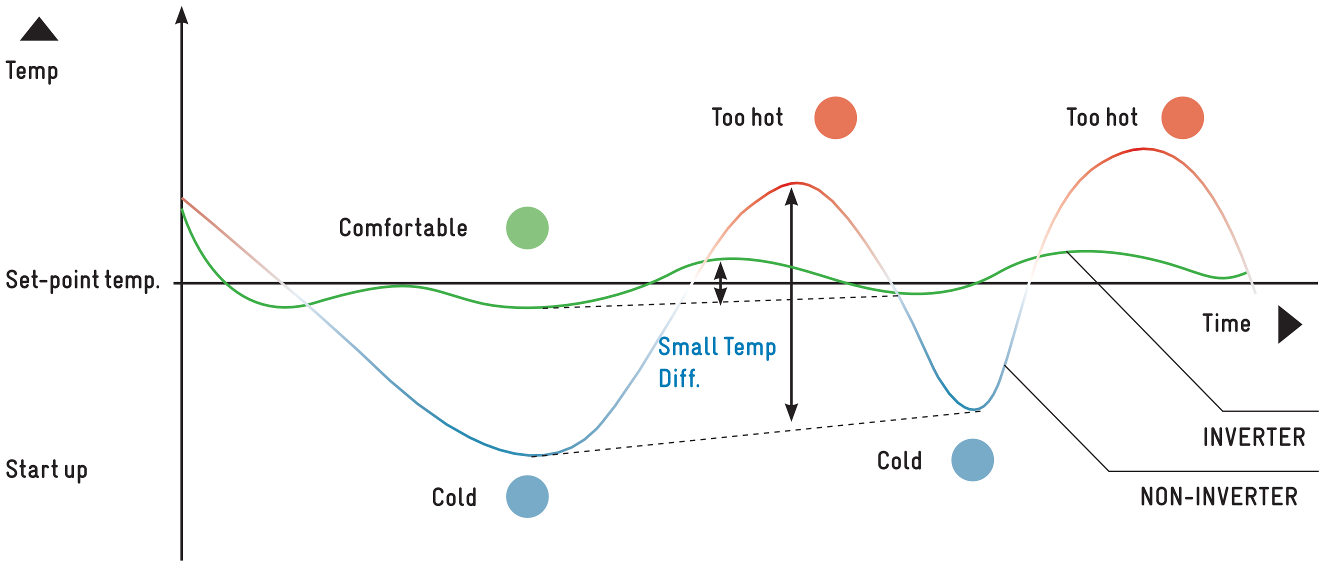


Figure 6: Comparison of fixed speed and inverter compressor behaviour (Godrej, 2018c)

Furthermore, a careful matching of the compressor capacity according to the cooling needs and an appropriate refrigerant charge to ensure operation under the most favourable thermodynamic conditions can also have a significant effect on the performance. A selection of efficiency measures are presented in *Table 3* and further details on improvement options are compiled by Usinger (2016).

The online platform TopTen publishes a list of the best currently available split ACs in terms of energy efficiency in Europe and China. Park et al. (2017) and GIZ Proklima (2018a) have conducted studies to assess the cost, energy, and climate performance of the available equipment in relevant additional markets.

Table 3: Availability of components related to EE for medium- and low-GWP refrigerants in AC (TEAP, 2019)

Component	Applicable to ref circuit	Available today?	Presently in use?	Remarks	Necessary components	Max potential improve-ment	Incremental cost for RAC unit	Applicability to climate region		
								LAT	MAT	HAT
Compressors										
Higher efficiency	X	Y	Y	Mostly used for rotary				X	X	X
- Inverter driven	X	Y	Y	Mostly used for rotary	Inverter, dedicated compressor	20% to 30%	20%	X	X	X
- two stage compression	X	Y	L	Very limited availability		10%	10% to 20%	X	X	X
- motor efficiency controllers		Y	L	Standard		same	same	X	X	X
Energy-efficient fan mators										
- EC fan motors		Y	Y	Reduce energy, heat load	Controller	7% to 15%	15% to 25%	X	X	X
- variable/ fixed-speed		Y	Y					X	X	X
- optimized fan blades		Y	Y					X	X	X
-tangential fans		Y	Y	For indoor unit only				X	X	X
- improved axial fans		Y	Y	For outdoor unit only				X	X	X
Expansion devices										
- electronic expansion valves	X	Y	L		EEV and controller	15% to 20%	15%	X	X	X
-fixed orifice	X	Y	L		RAC heating	Less efficiency	negative	X	X	X
- capillary tubes	X	Y	Y		TEV	Heating mode	negative	X	X	X

Component	Applicable to ref circuit	Available today?	Presently in use?	Remarks	Necessary components	Max potential improve-ment	Incremental cost for RAC unit	Applicability to climate region		
								LAT	MAT	HAT
Heat exchangers										
– Microchannel condenser coil	Y	Y	Y	Only condenser	AL/AL	15%	negative	X	X	X
– Microchannel evaporator coil	N	N	N				Less cost compared to the fin and tube			
– smaller tube diameter for condenser coil	X	Y	Y	Y	CU/AL	10% to 40%	negative	X	X	X
– smaller tube diameter for evaporator coil		Y	Y	Y	CU/AL	10% to 40%	negative	X	X	X
Adiabatic condensers		Y	Very limited	Only in high ambient	Filter and water treatment	25% to 30%	20% to 35%			X
Pipe insulation		Y	Y	Normal practice	Pipe insulation	<2%	Standard	X	X	X
Refrigerant	X	Y	Y	See RTOC 2014, 2018	Refrigerant	See RTOC 2014, 2018	+/- depends on the region	X	X	X
Defrost techniques	Y	Y		For HP only	controller		HP	X	X	X
– hot gas, reverse cycle		Y	L	HP	4 WAY VALVE	negative	Heating	X	X	X
– resistance heaters for Heating		Y	Y	some regions	Electric heater	negative	Some areas	X	X	X
– on demand control		Y	Y		controller		same	X	X	X
Controls										
– dynamic demand controllers		Y	Y		standard		standard	X	X	X
Reducing head pressure	X	Y	Y		Var speed cond. fans, controller	2% to 3% per 1 K	various		X	X

(N = no; Y = yes; L = limited; X = applicable. LAT = Low Ambient Temperature; MAT = Medium ambient temperature; and HAT = High ambient temperature)

Table 3: Availability of components related to EE for medium- and low-GWP refrigerants in AC (TEAP, 2019)

MARKET INTRODUCTION OF GREEN ACs IN GHANA

"Transitioning the market from R22 and R410A directly to R290 as a sustainable solution for Ghana's growing AC market is promoted as one of the key climate measures in Ghana's Climate Action Plans."

Emmanuel Osae-Quansah, Head of climate change and Ozone department, National Ozone Officer, Environmental Protection Agency Ghana

Ghana has committed itself to abating climate-damaging refrigerants such as R22 and R410A from its AC market and transitioning instead to natural refrigerants by including the RAC sector in its NDCs to the *United Nations Framework convention on Climate Change* (UNFCCC) Paris Agreement. By increasing the market share of energy-efficient ACs using climate-friendly refrigerants, it is estimated that about 7.86 Mt CO_2 could be avoided by 2030.

The Green Cooling Initiative (GCI) is supporting the *Environmental Protection Agency* (EPA) in preparing the market introduction of energy-efficient R290 split ACs in Ghana. In cooperation with the local AC dealers, the project is currently introducing 380 R290 split ACs to the market. To ensure the safe market introduction of this new technology in Ghana, Midea, and GIZ have jointly trained the AC dealer's technicians to safely handle this new but flammable refrigerant during installation, servicing, and repair.

Midea representative providing lectures on R290 split AC to Ghanaian technicians as part of the market introduction in 2018

2. Technical particularities of R290 split ACs and their safety features

In order to start adopting a new AC refrigerant, manufacturers have to balance different criteria, including thermodynamic performance (e.g., capacity, temperature, and efficiency), safety conditions (e.g., pressure, toxicity, and flammability), and compatibility with system materials, availability, cost, and environmental impact (Park et al., 2019) as well as commercial lifetime, which is influenced by (international) regulations and cost implications.

The use of R290 as refrigerant for single-split AC systems constitutes some peculiarities for the system design. Since historical use of higher flammability refrigerants has been limited, the flammability of R290 presents new considerations. In addition to the other hazards such as electrical, pressure and other mechanical aspects, flammability also has to be considered during the development of the system to ensure safe products.

2.1. R290 refrigerant

The hydrocarbon propane (C_3H_8) is a naturally occurring substance. Through the decomposition and reaction of organic matter over long periods of time, a variety of hydrocarbons were formed in the depths of the earth. Various hydrocarbons are separated from other petrochemicals and refined for a variety of commercial uses. Propane is often sold in cylinders and tanks as liquefied petroleum gas (LPG), for use as a fuel in heaters, cookers, etc.

Thanks to its favourable thermophysical properties, propane can be used as an energy-efficient refrigerant and has been assigned the refrigerant designation "R290". *Table 4* lists various thermophysical properties of selected refrigerants often used in split ACs, as a means of comparing their potential to achieve high efficiency.

In general, cycle efficiency is influenced by such properties which help to reduce pressure losses and improve heat transfer. Specifically, these include:

- High critical temperature
- Low liquid and vapour viscosities
- High liquid specific heat
- High liquid and vapour thermal conductivities
- High latent heat.
- Low change in pressure with saturation temperature

It can be seen that across these common refrigerants, R290 exhibits the most desirable properties.

Refrigerant	Critical temperature (°C)	Latent heat (kJ/kg)	Liquid specific heat (kJ/kg K)	Liquid thermal conductivity (W/m K×10^3)	Vapour thermal conductivity (W/m K×10^3)	Liquid viscosity (Pa s ×10^6)	Vapour viscosity (Pa s ×10^6)	Sat pressure-temp gradient [bar/K]
R22	96.1	183	1.26	83.5	11.3	164	12.5	0.28
R32	78.1	271	1.94	125.9	15.0	114	12.8	0.45
R410A	71.3	186	1.71	89.2	15.7	118	13.7	0.39
R290	96.7	336	2.72	93.7	19.0	97	8.2	0.24

Table 4: Comparison of various thermo-physical properties of selected refrigerants at 25°C (except critical), [Lemmon et al, 2018]

A high degree of purity and a very low water content have to be guaranteed in order for it to be suitable as commercial refrigerant. Respective requirements are summarised in *Table 5.*

Component	Limit Value	
	AHRI 700	DIN 8960
Composition:		
Propane	≥ 99.5% weight	≥ 99.5% volume
C3 and C4 saturated hydrocarbons	≤ 2% weight	
Isobutane		≤ 0,44% volume
n-butane		≤ 0,15% volume
unsaturated C4 compounds		≤ 0,01% volume
Odour (sulphur mercaptan)	None	
Water content	≤ 10 ppm weight	≤ 12 ppm weight

Table 5: Commercial specifications of the refrigerant according to standards AHRI 700 and DIN 8960

An ISO 817 safety classification of A3 means that R290 is of low toxicity but is flammable. R290 is flammable only within a certain concentration range when mixed with air. The range is illustrated in *Figure 7.*

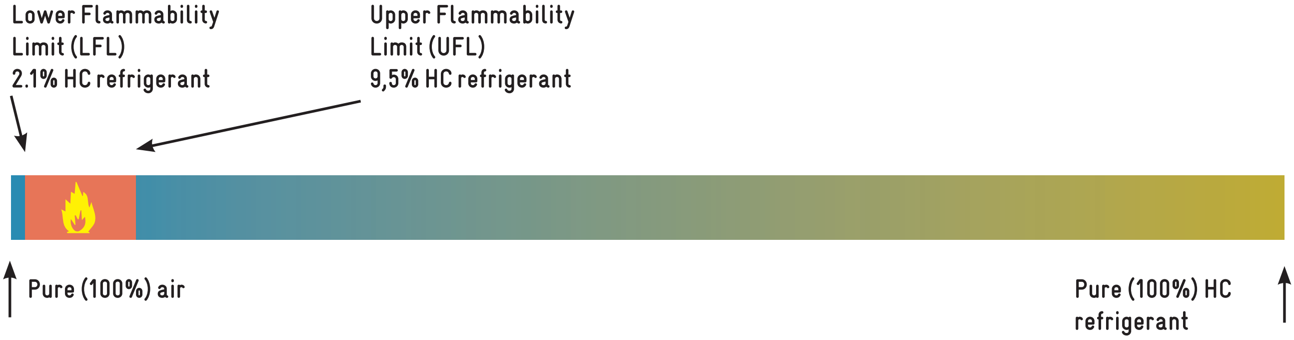


Figure 7: Flammability range of R290

To avoid the possibility of ignition, the amount of R290 used in a system should be limited such that in the event of a leak, a flammable mixture should not accumulate. This is usually achieved by limiting the system charge according to a quantity corresponding to some fraction of the lower flammability limit (LFL) of the closed spaces. Previously a value corresponding to one-fifth of the LFL (or "practical limit") was used in the safety standard for RACHP systems, EN 378-1, but as more research is carried out and the understanding of refrigerant leakage and dispersion behaviour are advancing, along with interaction with various mitigation measures, different factors, ranging from 20% to 50%, may be applied accordingly; see section 4 for further insight into this topic.

Integrated into these safety concepts is the recognition that R290 is heavier than air, which means that it will accumulate near the ground in the event of a leakage.

Specific approaches for identifying such limits are addressed in *Chapter 4.*

A flammable mixture only ignites, if there is a sufficient energy source to start the reaction such as a spark, an open flame or a hot surface. Ignition of R290 will result in various combustion products, primarily carbon monoxide (CO), carbon dioxide (CO_2), and water (H_2O). An R290 fire should only be fought with CO_2 or dry powder extinguishers.

Safety guidelines are not only applicable during the design phase (*Chapter 2.2*) and production phase (*Chapter 3*) of a split AC but also regarding storage, transport and installation area of the equipment; the whole lifetime of the equipment should be addressed.

Safe handling of refrigerant cylinders

For handling and transporting R290 cylinders, ideally local regulations for liquefied petroleum gas (LPG) must be followed. If there are none, at least the following measures have to be taken in order to prevent any accidents:

- Correct naming and distinct "flammable" marking on cylinders and transportation vehicles
- Store and use in ventilated areas away from ignition sources (avoid exposure to heat, no smoking)
- Safe transportation in upright, capped and secure position (protect valve)
- Use of goggles and gloves when handling R290 to minimise the possibility of frost bite from contact with liquid as with handling any other refrigerant.

Local production and supply of R290 in Indonesia by PT Pertamina

In Indonesia, state-owned oil and natural gas corporation, PT Pertamina, is a local producer and supplier of propane. At their refinery in Palembang, LPG is extracted from crude oil and then used as fuel gas. Through further purification steps, propane is also processed to suitable industrial gas as well as refrigerant gas. At three filling stations in Indonesia, R290 is bottled and then distributed across the country.

The company has supplied refrigerant for several hydrocarbon chillers and expects a growing supply of R290 AC appliances

Filling station for R290 refrigerant in Jakarta, Indonesia (© PT Pertamina)

2.2. Specific technical features for R290 split AC

Differences in the design of R290 split ACs, compared to those using conventional refrigerants, are related to differences in thermophysical properties and mitigation of flammability hazards. A major feature is the selection and design of components that enable minimisation of the refrigerant charge size whilst maintaining high energy efficiency. Using R290 requires manufacturers to optimise AC systems by changing compressors (including compressor oil), heat exchangers (to match the refrigerant's properties), and expansion device. The combination of the favourable thermophysical properties of R290 and improved heat exchanger design allows the minimisation of the refrigerant charge, per unit of cooling capacity, compared to conventional refrigerants.

Other measures aimed at reducing flammability risk consists of improved tightness, elimination of ignition sources, features to enhance dispersion of leaked refrigerant and controls to limit the releasable charge amount. *Figure 8* illustrates the principal considerations for minimising ignition risks, whilst particular technical features are shown in *Table 6*, that should be considered for R290 split ACs:

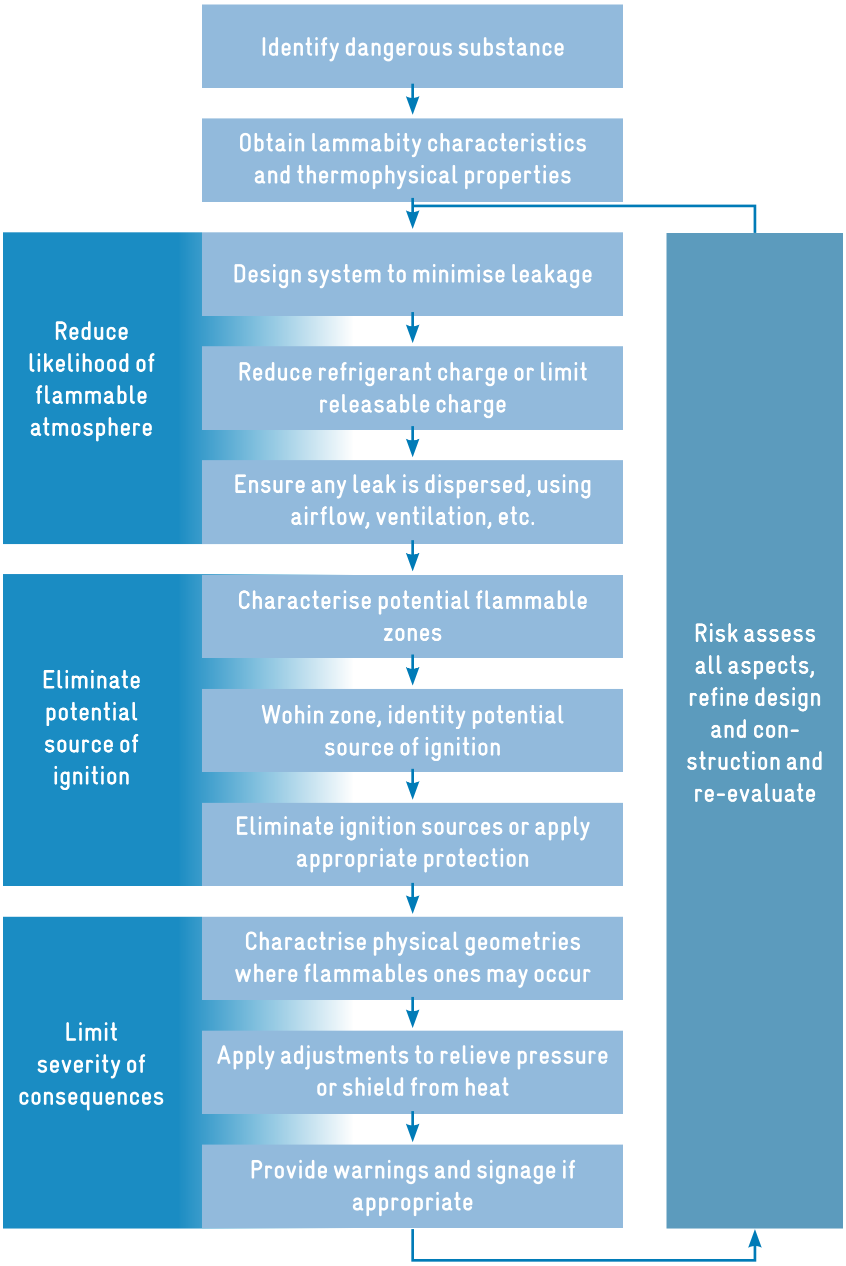


Figure 8: Principal design approach for explosion protection (GIZ Proklima & TÜV Süd, 2010)

Ensure good system tightness

esign and manufacture the refrigerant circuit with as many features as possible to minimise the possibility of refrigerant leakage within the occupied space(s). For example:

- No detachable joints (particularly for indoor parts)
- Brazed connections (e.g. instead of flare joints)
- Protection from external mechanical damage
- Minimise transmission of vibrations from compressor, fans, etc.
- Avoid possibilities for corrosion
- Use approved circuit components
- Leak detection test proved tightness of components, piping, and connections.
- Rigorous production and quality control

Avoid potential sources of ignition associated with appliance

Design and construct the AC to ensure that if a leak was to occur, refrigerant would not be exposed to any potential source of ignition associated with the unit. For example:

- Use non-sparking or Ex-type parts[7]
- Use plastic instead of metal fan blades and a brushless electric motor to avoid sparks from contact with cowling panels
- Put main contactors in separate panels or use solid state contactors
- Ensure relays are encapsulated
- Any hot or sparking components are positioned away from wherever any refrigerant leak could flow to or accumulate, as determined by carrying out a leak simulation test.

Add leak detection

Some form of leak detection system may be integrated into the product so that flammability mitigation measures can be activated. For example:

- Gas detector
- Ultrasonic receiver that detects the sound produced when a leak occurs
- Monitor system parameters (pressure, temperature, compressor current, etc.) that indicate a deficit of charge.

When a leak is detected, protective measures can be initiated, such as de-energising the compressor, switching on the IDU and ODU fans and/or closing safety solenoid valves to prevent the entire refrigerant charge from being released from the IDU.

7 According to IEC 60079-series

Enhance dispersion of leaked refrigerant

- Ensure sufficient air flow rate to dilute R290 in the event of leakage
- Optimise unit housing design so that exiting concentrations are minimised.

Minimise refrigerant charge

- Minimise the flammable refrigerant charge quantity while retaining high energy efficiency e.g. low volume exchanger headers, and use of smaller tube diameters for heat exchangers.
- Compressors with smaller internal volumes and which use lower solubility oils

Use of solenoid shut-off valves

- In the event of a leak, a shut-off valve in the liquid or delivery line and where necessary in the suction or discharge line, which can close in order to prevent flow of refrigerant from ODU to the possible leak hole in the IDU.
- Such valve(s) should be normally closed so that during off-mode the refrigerant is automatically prevented from flowing towards the leak.

Inform about flammable refrigerant

Ensure that anyone initiating work on the system is made aware of the presence of flammable refrigerant inside and as far as possible the precautions they should take.

- Flammable refrigerant signage visible on indoor and outdoor unit
- Flame symbol and instruction manual symbol on parts subject to maintenance or repair
- Warning label for room requirement
- Installation/service/operation manual
- Signage and instruction for transportation on packaging for pre-charged equipment.

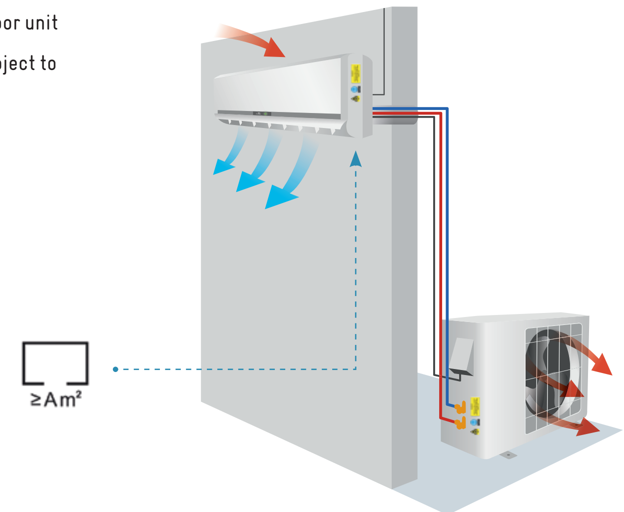


Table 6: Technical safety features for R290 split AC units; adapted from (adapted from GIZ Proklima (2010) & Caravatti (2018))

As addressed above, the split AC system has to be specifically designed to ensure minimal flammability risk. Using R290 as drop-in refrigerant for existing R22 systems or any other system poses a greater safety risk as the appropriate technical features are not necessarily in place. Additionally, drop-ins might affect the efficiency and lifetime of system components such as compressors, which are designed for particular refrigerants and their properties. Therefore, simply refilling existing HCFC or HFC refrigerant-based appliances with R290 is strongly advised against.

In addition, any split AC needs to have a data-plate on both indoor and outdoor unit. These labels provide important technical information to any AC technician working on the system. *Figure 9* and *Figure 10* show examples for the required information on the labels.

Figure 9: Example for label on IDU

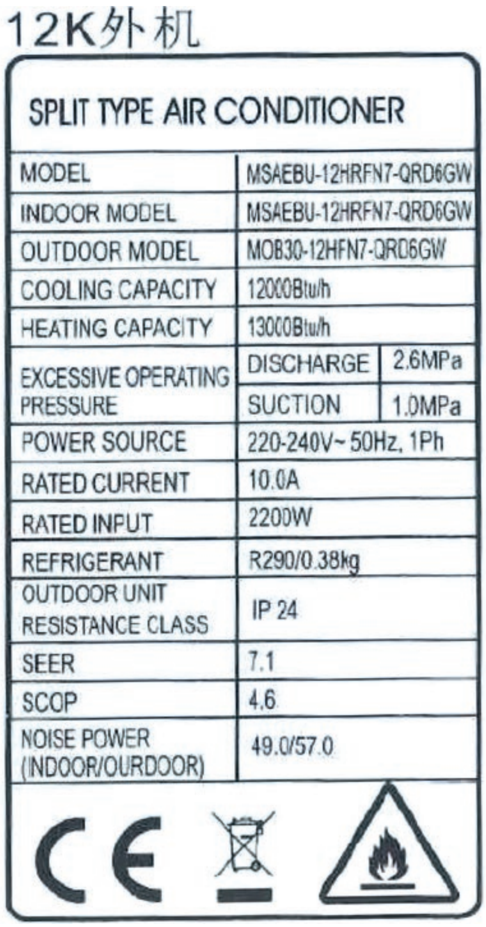


Figure 10: Example for label on ODU

References and relevant resources:	
Split AC market assessment	GIZ Proklima (2018), Cost, energy and climate performance assessment of split ACs in Asian Countries (market assessment for other countries in Africa and Latin America available upon request) Park, Shah and Gerke (2017), Assessment of commercially available energy efficient room air conditioners including models with low global warming potential (GWP) refrigerants (study by Lawrence Berkeley National Laboratory; focus on China, Europe, India, Japan, South Korea, and the United States) Best available air conditioners in Europe (TopTen EU) and in China (Top10 China)
Technical Safety Features for R290 split ACs	GIZ Proklima (2012), Guidelines for the safe use of hydrocarbon refrigerants, Part 5: Equipment Design and Development GIZ Proklima (2008), Natural Refrigerants: Sustainable Ozone- and Climate-Friendly Alternatives to HCFCs, II. Safety of Natural Refrigerants p. 95f
Technical Safety Features for R290 split ACs	GIZ Proklima (2012), Guidelines for the safe use of hydrocarbon refrigerants Godrej, Training Manual for Godrej Split Air-Conditioners with Hydrocarbons (R290 refrigerant), Chapter 3.1 (available upon request)
Technical and economic assessment of R290 split ACs	GIZ Proklima (2022) https://www.green-cooling-initiative.org/news-media/publications/publication-detail/2022/10/25/can-refrigerants-with-a-gwp-below-150-be-used-for-heat-pumps-in-europe Colbourne, D., Suen, K. O. 2015. Comparative evaluation of risk of a split air conditioner and refrigerator using hydrocarbon refrigerants. Int. J. Retrig. vol. 59 https://www.sciencedirect.com/science/article/abs/pii/S0140700715001978 Rajadhyaksha, D., Wadia, B. J., Colbourne, D. 2015. The first 100,000 HC-290 split air conditioners in India. Int. J. of Refrigeration, vol. 60, 10.1016/j.ijrefrig.2015.07.032
Safety standard	IEC 60335-2-40: 2022 (7th edition)

LOW-CARBON AIR CONDITIONING THROUGH R290 SPLIT ACS IN COSTA RICA

Costa Rica is a global model and front-runner in transitioning to climate-friendly technologies and practices. Nevertheless, the use of advanced space cooling technology with low-GWP refrigerants has not been well established in the market. This can also be seen in the RAC sector's significant share of 12% (in 2012) of the country's total GHG emissions. By using R290 instead of HFC refrigerant in AC systems, Costa Rica can significantly reduce its HFC emissions and thereby further contribute to its ambitious low emission development path.

As part of the Cool Contributions fighting Climate Change (C4) Project in Costa Rica, the Ministry of Energy and Environment in cooperation with the GIZ imported energy-efficient R290 split ACs for demonstration and trainings of AC technicians. The appliances are installed in various types of buildings, including hotels and government buildings.

The project is implemented in a close cooperation with ICE, one of the national electricity utilities in Costa Rica. More information on the project can be found on: https://www.international-climate-initiative.com/en/project/cool-contributions-fighting-climate-change-c4-15-i-242-global-g-cool-contributions-c4/

"In a changing world, where the industry seeks day to day to meet the technological needs of people, to be at the forefront of new options is essential. Costa Rica has taken important steps in this line on issues such as: renewable generation, electric vehicles, and decarbonisation of the economy. Now it is time to take the step to new options of air conditioning where R290 refrigerant will be an indisputable protagonist. It will be indispensable for our country to know all the benefits of this gas and to be trained in its use and its applications."

Marvin Donel Zuñiga Alvarez, Engineer from Ensayos, Laboratory of Energy Efficiency

Costa Rican technicians installing Godrej R290 split AC at the Climate Change Office of the Ministry of Environment and Energy (MINAE)

3. Production of R290 split ACs

Up to now the actual production of R290 split ACs is still low compared to the global volumes of split AC unit sales. The capacity to manufacture R290 units is so far limited to China and India. There are several tens of production lines already converted to manufacturing R290 split ACs. In India, the local manufacturer Godrej & Boyce (hereafter: Godrej) is commercially producing R290 split ACs – mainly for the domestic market – with over one million units sold to date. Several Chinese manufacturers transformed production lines, among them Midea, Haier, TCL, Gree, Hisense, Changhong, AUX, and Yair. Such units are now being marketed in Europe. Millions of portable/movable room AC units are being produced each year with R290.

During the first and second stages (2013 to 2019) of China's HCFC Phase-out Management Plan (HPMP) with funds of the Multilateral Fund, China has already converted 23 room AC production lines to R290 making up for a production capacity of 5,000,000 units per year. Seven room AC compressor production lines have been also converted to R290 with a production capacity of 10,000,000 units per year. MLF, 2020 [HCFC-22 Phase-out Management Plan for the Room Air Conditioner and Residential Heat-pump Water-heater Sector in China, Updated for 2021 to 2026]). Other countries, e.g. Egypt (8 production lines), Pakistan, Brasil, etc. are about to convert productions lines under their stage II *HCFC phase out management plans* (HPMPs) of the Montreal Protocol.

Product development

- Ensuring a minimal space volume according to the refrigerant charge
- Avoiding any potential sources of ignition within the test spaces
- Fitting of an extract ventilating system of 500 – 1000 m^3/h
- Having one or more gas sensors to identify if and when a leak has occurred and to initiate extract ventilation
- Installing an emergency stop switch on the inside and outside of the rooms to terminate electrical power and also to initiate extract ventilation.

Basic Set-Up

Figure 11 illustrates the exemplary set-up of a split AC production line. The main components to assemble R290 split AC units are identical with any other split AC factory, so the conversion of existing conventional production lines for R22 or R410A technology can be realised with relatively little investment.

The main changes are related to incorporating and reinforcing safety measures with regards to handling flammable refrigerant in the facility. Areas where R290 is stored, charged or handled demand for specific risk mitigation strategies. The hazardous areas are highlighted in *Figure 11*. Safety measures include a good ventilation system, gas detection, and alarm, warning signs as well as a complete and automatic shut off in case of an emergency. The key areas in the R290 production line should be equipped with real-time monitoring systems and set with alarms. Appropriate training of the personnel to raise awareness of the risk and to instruct them on how to avoid dangerous situations is an essential complement along with the hardware equipment. In addition, assessments need to be undertaken in all areas of the production line to identify and avoid ignition risks caused by electrostatic charges.

Specifically, the following set-up including relevant safety features is recommended (GIZ Proklima, 2012):

- Gas sensors and alarm systems
- Ex-type electrical hardware in areas handling refrigerant
- Ventilation system in areas handling refrigerant.

Among the areas where specific safety measures need to be added for R290 are:

- Refrigerant storage area
- Refrigerant charging system
- Ultrasonic sealing of process tube
- Leak detection after charging
- Product performance test chamber and laboratory
- Product repair area.

References and relevant resources:	
Technical Safety Features for production line of R290 split ACs	GIZ Proklima (2012), Guidelines for the safe use of flammable refrigerants in the production of room air-conditioners
Finance Support for conversion of production line	GIZ Proklima (2018c), Coordinating finance for sustainable refrigeration and air conditioning

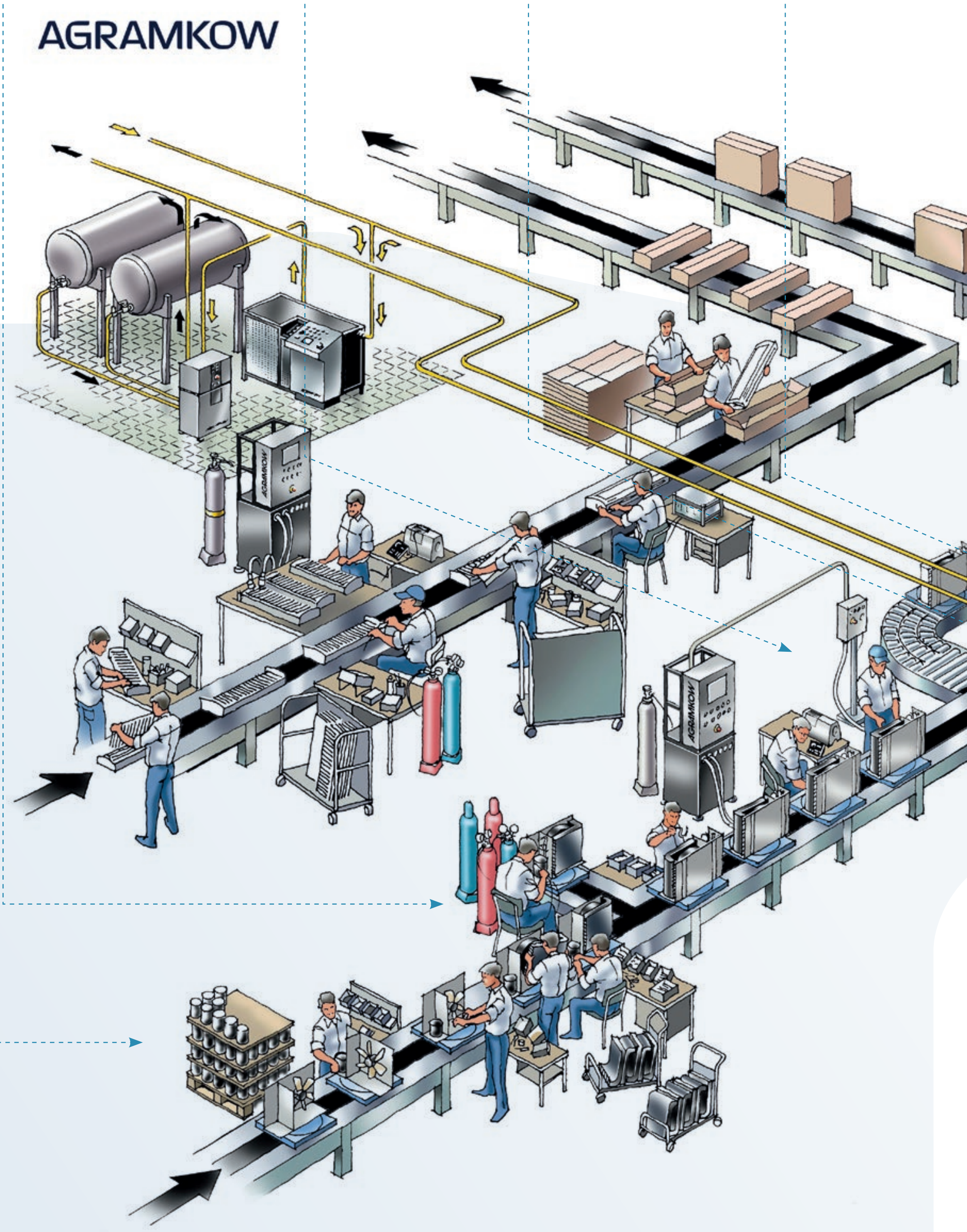
1. Srew Removal,
Earth Wiring,
Compressor Fitting

2. Brazing

3. High Pressure Testing
Helium Leak Test

4. Refrigerant Charging

5. Ultrasonic Tube Sealing



6. Leak Detection after Charging

7. High Voltage Testing

8. Case Fitting

9. Performance Testing Lab/ Operational Inspection

10. Visual Inspection Packaging

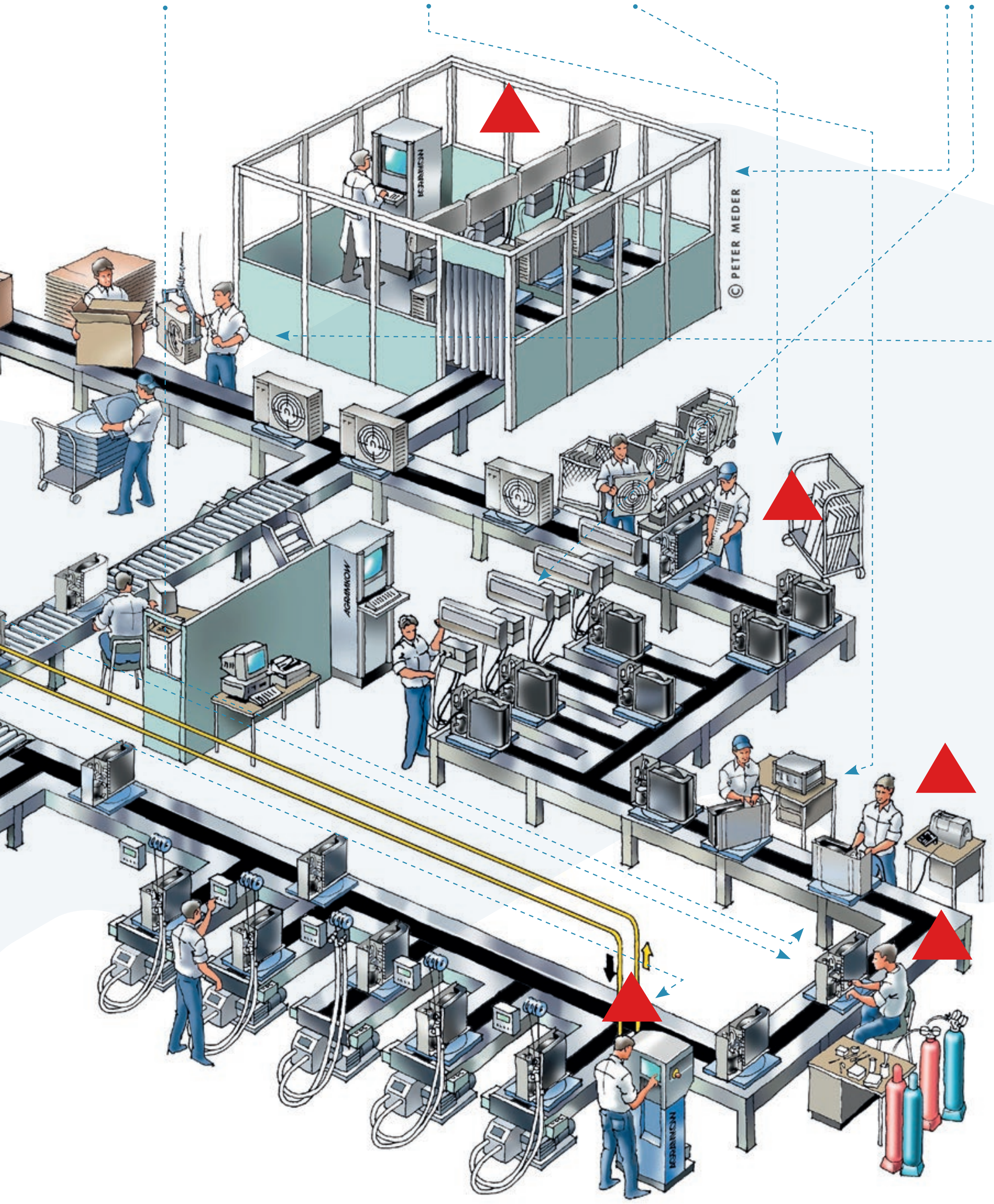


Figure 11: Exemplary set-up of an assembly line for non-flammable refrigerants and with safety areas required for R290 specified (red triangles) split air conditioners ODU; adapted from (© AGRAMKOW)

Production line conversion of R22 split AC to R290 split AC for Godrej

In 2012, Godrej converted one of its production facilities to assemble ODUs for R290 split ACs with support of GIZ Proklima. The area is equipped with the following equipment:

- R290 gas charging station and performance test chamber including ventilation ducting with two speed options as well as a gas alarm mechanism (placed on the ground) with complete power cut-off interlock.
- Repair area refrigerant gas recovery system with ducting and gas alarm interlock.
- Fire proof junction boxes in refrigerant charging areas.
- Equipotential grounding of all equipment has been done

Figure 12: Ventilation system of refrigerant gas charging station

Figure 13: Gas detector at gas charging station

Figure 14: Ventilation system and gas alarm of test performance lab

Figure 15: ATEX certified control panel

4. Safety standards for R290 split ACs

4.1. Safety standards for R290 split AC unit

The introduction of split ACs with R290 depends upon a set of technical standards, which adequately address flammability hazards. There are two international standardisation organisations that publish relevant safety standards with regard to the use of R290 in split-type ACs: The International Standardisation Organisation (ISO) and the International Electrotechnical Commission (IEC). Standards are also issued at national and regional level, for example in Europe: European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC). ISO 5149 and European Norm, EN 378 are horizontal or group standards covering overarching requirements based on common characteristics of RACHP systems. The product standard IEC 60335-2-40 specifically defines requirements for ACs and heat pumps.

These standards prescribe a number of different safety-related requirements, covering electrical safety, pressure safety, fire and flammability safety, controls, materials and a variety of other mechanical hazards; virtually all requirements are applicable to split ACs using almost any refrigerant. A few requirements specifically concern the use of flammable refrigerants and include the topics mentioned previously: improved system tightness, elimination of ignition sources, features to enhance dispersion of leaked refrigerant and controls to limit the releasable charge amount. One particular type of requirement for the application of R290 in split AC systems is the refrigerant charge size limit. [*see info box*]

Charge sizes of split AC systems with flammable refrigerants need to be optimised in order to maintain a tolerable flammability risk while ensuring high energy efficiency. *Figure 16*[8] provides an illustration of how the nominal cooling capacity of an AC system is related to its refrigerant charge for a range of different energy efficiency ratios (EERs), based on current HFC design technology. The diagram highlights the interdependence of system performance and required refrigerant charge. In general, it can be concluded that after all other measures have been implemented, a higher energy efficiency requires higher charge size due to greater heat exchanger size.

However, through implementation of further design features that are evolving for R290 split ACs, further charge reduction is being achieved, which further increasing system efficiency, as indicated with the "EER = 7.0+red" case in *Figure 16*.

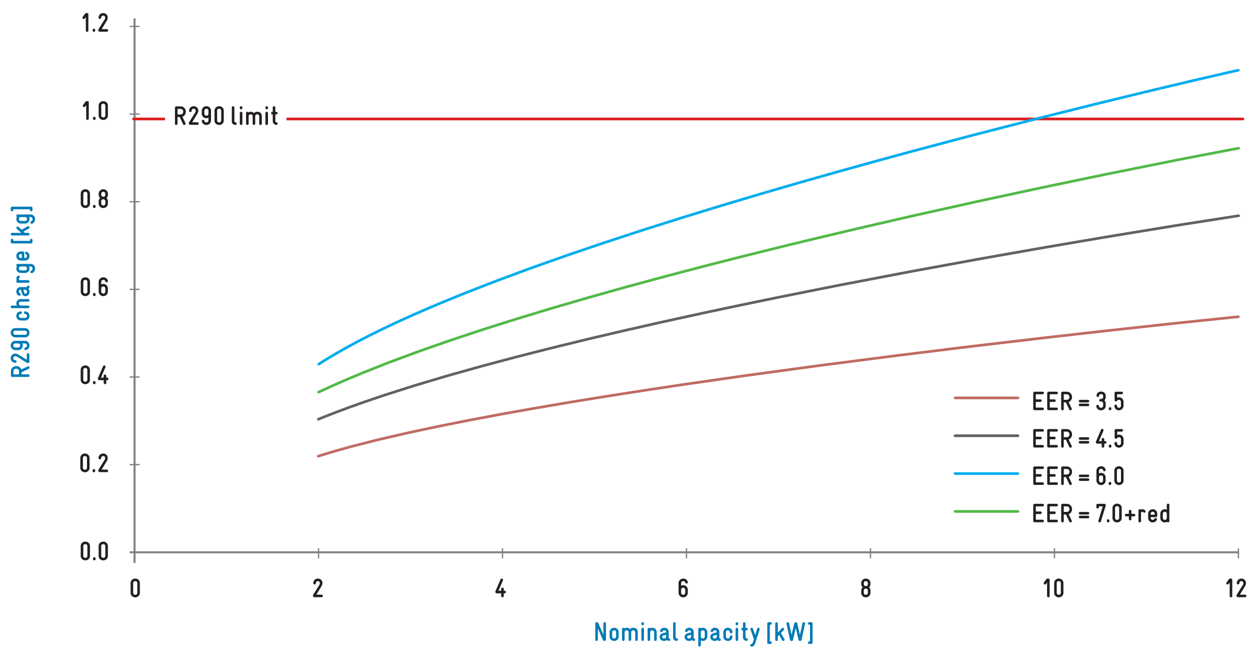


Figure 16: Example of the relationship between refrigerant charge and cooling capacity as a function of EER of an AC system with R290 adopted from GIZ Proklima (2022)

8 Note that in real systems, there is wide scatter across different models, heat exchanger type, manufacturers and AC

Current requirements for systems using flammable refrigerants

RACHP safety standards deal with a wide range of hazards associated with systems and equipment, besides refrigerant charge issues. Aspects related to refrigerant safety and the associated design, construction and handling requirements represent a large share of the addressed hazards. *Table 7* provides a summary of the important topics handled by RACHP safety standards that are relevant for the use of R290 split ACs. Generally, if a product falls into the scope of a product standard, then that standard should be used. However, if a horizontal/group standard is more up to date or more relevant and can be suitably applied to the product then it can also be used. Depending upon the national framework, clauses can be "mix-and-matched" from different sources as appropriate. Further, these standards are continually under revision and are expected to contain changes regarding charge size and flammability safety measures as the industry and use of HC refrigerants evolves.

Category	IEC 60335-2-40
	EN 60335-2-40
Scope	Factory-made whole ACs, heat pumps and dehumidifiers and partial units thereof
Limits on refrigerant charge amount	Approx. 1 kg of hydrocarbon refrigerant in a direct system inside (depending on room size) and 5 kg outside or within a special enclosure
Marking	Requirement of flammability warning symbols
Strength pressure	Specification of pressure tests for systems and components (where applicable)
Electrical equipment	Specification of design, construction, and test requirements
Sources of ignition	Description of what to consider and how to avoid a potential source of ignition, including a test method option
Information & instructions	Details concerning the installation, use, service, maintenance, and disposal of the equipment so that users, operators, and technicians are aware of how to handle flammability hazards
System tightness	Systems generally have to be constructed as "sealed" or "hermetically sealed" systems if they are to use flammable refrigerants indoors (e.g. no or limited number of non-permanent mechanical connections or fittings)
Pressure limiting/ relief devices	The need for additional devices to limit or relieve excess pressure may apply to smaller systems when flammable refrigerants are used
Secondary/ indirect systems	Additional components for secondary or indirect refrigerant circuits (such as those using water or brine) are required to vent a leak that has occurred from the evaporator into the secondary circuit if the primary refrigerant circuit exceeds a certain charge size
Leak detection	Leak detection is mandated for certain situations to initiate mitigation measures such as airflow or closing shut-off valves, terminating electrical supplies, etc.

Table 7: Summary of general technical obligations under safety standards for AC and HP systems[9]

Within RACHP safety standards, the permissible amount of flammable refrigerant is handled by means of so-called "charge limits". The charge limits are intended to avoid excessive quantities of refrigerant from being leaked into a space such that a flammable mixture persists and is thus vulnerable to being ignited by source within the local area. This is handled by a so-called "allowable charge limit" which is formulated to prescribe the maximum quantity of refrigerant that may be released into a space such that the LFL will not be reached. The quantity is a function of the equipment characteristics, also accounting for the effect of any mitigation measures that have been integrated into the design or installation of the equipment. The formulation of the calculation takes into account anticipated variations in such factors so that it is always erring on the side of caution.

In addition to the allowable charge limit is the capped or "maximum charge limit", which is an arbitrarily set value, broadly selected as to confine the framework of the standard to within a range that the requirements are deemed relevant for. Unlike the allowable charge limit, the maximum charge limit is a fixed value, set at about 1 kg of R290 for equipment (or parts of equipment) installed indoors and 5 kg for outdoor equipment or indoors when installed within a special ventilated enclosure.

9 This is a summary of the key requirements. More details on requirements can be found in the standard documents themselves.

In contrast to earlier editions, the current edition of IEC 60335-2-40: 2022 permits larger quantities of HC refrigerants per unit of room floor area. Greater quantities of refrigerant are allowed on the condition of additional mitigation measures intended to lower concentrations of refrigerant leaked into the room. Essentially these mitigation measures include improved system tightness, provision of airflow to disperse leaks and integration of valving to limit the amount of refrigerant that could leak from the system. In summary:

- Enhanced tightness refrigeration system (ETRS), where assumed leak rate is generally smaller than non-ETRS. In this case, allowable charge limit (ACL) is equation (1).

$$m_{ACL} = F \times LFL \times h_0 \times A_{rm} \quad (1)$$

where the concentration factor, F = 0.35.

- Systems which use integral circulation airflow (IAF), where the IDU fan operates continuously or in response to leak detection, so that any release will be disperse almost homogeneously throughout the room and thereby avoiding any formation of a potentially flammable mixture. Leak detection may be applied in connection to leak indicators (e.g. use of gas sensors, ultrasonic detection, or system parameters), so airflow can be activated on demand. Systems may be ETRS or non-ETRS; this only affects the required minimum airflow rate to disperse a leak. The ACL is equation (2).

$$m_{ACL} = F \times LFL \times h_{rm} \times A_{rm} \quad (2)$$

where the concentration factor, F = 0.50.

- Limited releasable charge, where, if the releasable charge can be determined by test, the resulting mass can be assumed rather than the charged amount (equation 3). Whilst not specified in the standard, this can be considered to fall into two categories:
  - "Passive" limited releasable charge (PLRC), which typically accounts only for the mass retained in refrigerant oil and the system volume at atmospheric pressure, and
  - "Active" limited releasable charge (ALRC), which employs features such as safety shut-off valves to hold charge within the outdoor unit in response to leak detection. Again, Leak detection may use gas sensors, ultrasonic detection or system parameters, so valves are closed on demand.

In either case, the releasable charge can be expressed as equation (3).

$$mRC \cong (1 - \vartheta) \times m_C \quad (3)$$

where the retained charge coefficient, ϑ, may be around 0.8 – 0.9 for PLRC and anywhere from 0.05 to 0.75 for ALRC; in either case, it must be determined using the test method described in the standard, for the particular product. For ALRC, the smaller the internal volume of the indoor part of the system (relative to the whole system) and the faster the response time of the leak detection system, the lower ϑ will be.

- ACL calculation for the basic method (as included in previous editions of the standard) is equation (4).

$$m_{ACL} = 2.5 \times LFL^{1.25} \times h_0 \times \sqrt{A_{rm}} \quad (4)$$

Quantification of these charge limits for R290 with respect to room area where the R290 split AC is installed, are shown in *Figure 17*, where for ALRC cases it is assumed that ϑ = 0.4. In the figure, most charge limits (i.e., ETRS, IAF and ALRC) are above the basic limits for floor, wall and ceiling units.

Figure 17: R290 system charge limits as a function of room floor area

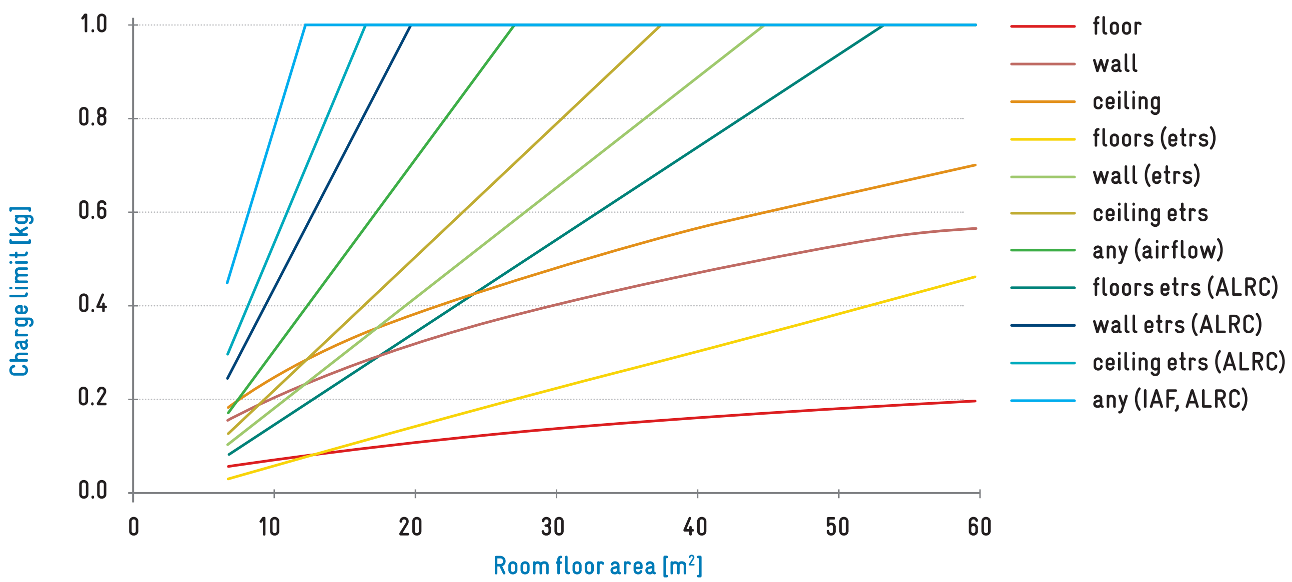


Figure 17: R290 system charge limits as a function of room floor area

Figure 17 translates *Figure 18* into charge limit as a function of cooling (or heating) capacity, where a thermal load of 200 W/m² has been assumed. Expressing the charge limits in this way provides more relevance to the application, although the same observations can be made as with room area.

As described above, current RACHP safety standards tend to rely on two types of constraints for refrigerant charge amounts: (i) the maximum charge being an overall cap according to the application and location of the system, and (ii) an allowable charge as a function of room size, installation height of the equipment, design of the system and use of airflow to help disperse leaks. While these types of standards put constraints on the application of R290 split ACs, they are considerably less obstructive than previous editions of the standard and it is expected that future editions will be further refined.

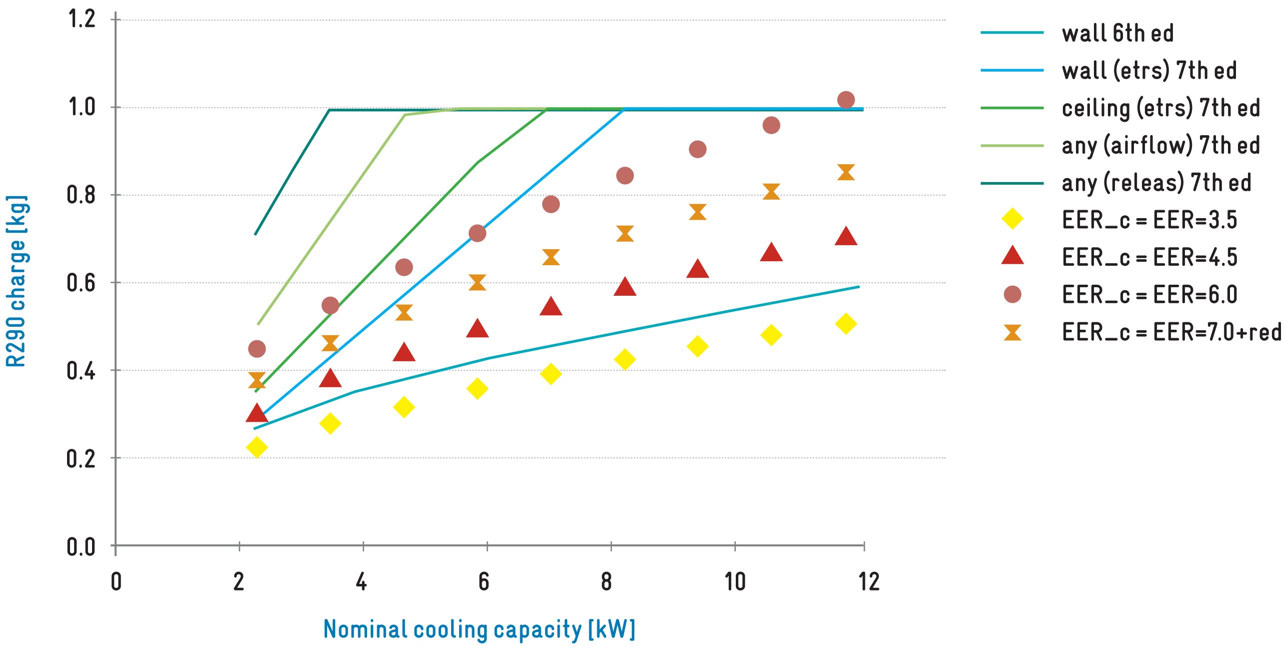


Figure 18: R290 system charge limits as a function of room floor area

Installation Height [m]	0.6	1	1.4	1.8	2.2	2.6	3

Nevertheless, further refinements and improvements to the standard are desired and activities are underway accordingly. Countries who host stakeholders with an interest in the uptake of R290 split ACs should be encouraged to become active in the process, such that subsequent versions of the standard, as well as national adoptions of the international standard, suitably reflect the needs of the equipment producers, end users and national climate policies.

References and relevant resources	
Relevant safety standards	• IEC Standard 60335-2-40 • ISO 5149 Standard
Guidance on national process to modify safety standards	• GIZ Proklima (2023), International Safety Standards in Air Conditioning, Refrigeration & Heat Pump • Environmental Investigation Agency (EIA) (2017), Smarter Standards: Vital for Kigali Amendment Success

Advancing safety standards for R290 split AC

Besides accelerating their efficiency levels, split AC systems need to use refrigerants with a particularly low GWP in order to achieve national obligations under the Kigali Amendment. To enable this, safety standards need to be written in a manner that not only ensures safety, but also does not obstruct technology or impose unnecessary or costly requirements; they need to be written in a way that facilitates rather than hinders innovation. Previous editions of IEC 60335-2-40 were indeed obstructive, whilst the latest edition (of 2022) has eliminated the majority of the previous obstructive requirements and is considerably more flexible and inclusive for hydrocarbon refrigerants. Nevertheless, further refinements and improvements to the standard are desired and activities are underway accordingly. Countries who host stakeholders with an interest in the uptake of R290 split ACs should be encouraged to become active in the process, such that subsequent versions of the standard, as well as national adoptions of the international standard, suitably reflect the needs of the equipment producers, end users and national climate policies.

The IEC standards development process allows for a wide participation from countries that maintain an IEC membership. Countries participate through membership of their national committee (NC), either as P-members, who must send experts to participate in technical meetings, or as O-members with a lower level of participation required. Each national committee has one vote on a given technical committee (TC) or sub-committee SC).[10]

10 For the standard IEC 60335-2-40, the responsible technical Sub-committee IEC SC 61D on safety of air conditioners and heat pumps set up a Working Group, WG16, in 2015 specifically to address requirements for A2 and A3 refrigerants under IEC 60335-2-40, including R290 in split ACs. In 2019 the WG16 transitioned to a new one, WG21, so that all flammable refrigerants could be addressed (not only class A2 and A3). In 2022 there was a unanimous approval of member countries for the proposed draft standard and thus the 7th edition of IEC 60335-2-40 was adopted and published in 2022. Since then, there has been a new group, Maintenance Team MT28 set up, which will work on amendments and revisions of the standard on a continual basis.

Safety compliance of R290 split ACs in India

On behalf of *Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety* (BMU), GIZ assisted the AC manufacturing company Godrej & Boyce in India in converting their production from R22 to R290 split type ACs. The project built on Godrej's existing experience with hydrocarbons (R600a) in domestic refrigerators since 2001. GIZ assisted Godrej in designing the unit according to necessary safety features, as well as in converting one of its production lines. The current production capacity of R290 split ACs is 300,000 units per year.

Following the charge limits specified in the standard IEC 60335-2-40, the planned unit with 5 kW cooling capacity allowed a maximum charge of 360 grams. Technology features like microchannel heat exchangers allowed the company to reduce charge sizes to within the charge limit, while ensuring high efficiency at the same time (Godrej, 2018b). Larger charge sizes in combination with adequate safety measures would allow for efficiency gains, and higher capacities for larger room sizes.

4.2. Product safety testing of R290 split ACs according to safety standards

When developing a R290 split AC, it is appropriate to carry out certain testing to ensure the intended function. This testing comprises several categories:

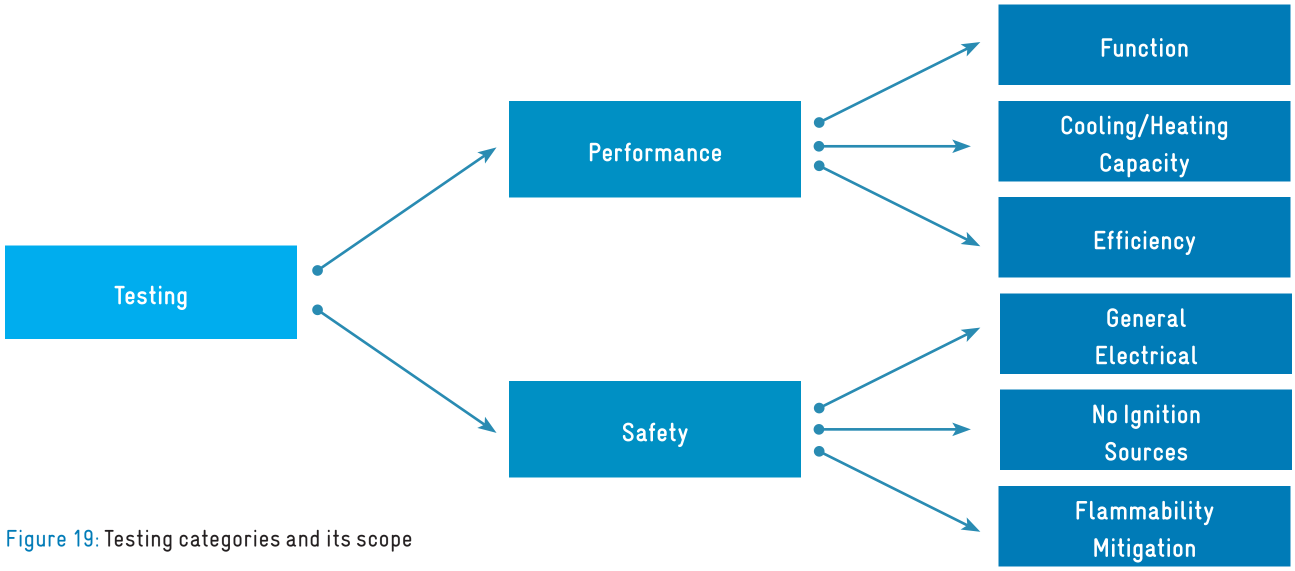


Figure 19: Testing categories and its scope

IEC 60335-1 and 60335-2-40 include a variety of tests for determining the electrical safety of split AC, such as creepage distances, current draw, earthing/continuity, etc. The majority of these tests are usually applied to most RACHP products, irrespective of refrigerant and are thus well known.

There are a number of other tests which are less commonly applied or are being newly developed for use with flammable refrigerants, some of which are described in the safety standards and others which are more embryonic. These include tests which are used to:

- Demonstrate that potentially arcing and sparking components are not located where leaked refrigerant could accumulate (e.g. IEC 60335-2-40: 2022 Annex FF)
- Prove the effective function of leak detection systems and initiation of mitigation measures (IEC 60335-2-40: 2022, Annex PP)
- Identify the maximum releasable charge in the event of a leak (IEC 60335-2-40: 2022, Annex QQ).
- Verify that the floor concentration below or surrounding the appliance does not reach the LFL in the event of a leak (e.g. Annex CC of IEC 60335-2-89: 2019[11])

Along with a test such as that of Annex CC, other functional features such as use of circulation airflow for dilution of a release, use of the releasable charge, etc., can be incorporated to test protective measures applied for flammability safety.

11 Whilst this is within the commercial refrigeration standard, it can be used for producers of R290 split ACs to evaluate and

FIRST NATURAL REFRIGERANT SPLIT ACS IN THE CARIBBEAN

The Caribbean heat on Grenada and Carriacou makes air conditioners necessary to ensure comfort at home. However, conventional air conditioning units used here are traditionally energy-intensive and use high-GWP refrigerants. In the last years, there have been increasing efforts on the island to introduce more environment-friendly cooling devices, for example by using R290.

In order to facilitate the market introduction of R290 in split ACs, 30 highly energy-efficient R290 split ACs were imported to Grenada by the National Ozone Unit of the Ministry of Infrastructure Development in cooperation with GIZ as part of the Cool Contributions fighting Climate Change (C4) Project. These R290 split ACs are now used for training of RAC technicians and for a demonstration project on monitoring and evaluating of the energy performance of these units in various fields of application, such as hospitals, government buildings, schools and private buildings. The results so far have been impressive.

More information on climate-friendly cooling in Grenada can be found on:
https://www.international-climate-initiative.com/en/iki-media/video/green-air-conditioners-for-tropical-grenada

"Small Island States that are particularly vulnerable to the impact of global warming and adverse environmental events must find solutions to mitigate against global increase in atmospheric temperatures. The introduction of air conditioning units in the RAC sector using natural refriger- ants with zero ODP and ultra-low GWP, clearly demonstrates definitive action at the national level to address an environ- mental scourge and to promote an environmentally healthy lifestyle."

Leslie Smith, National Ozone Officer, National Ozone Unit Grenada

R290 split AC unit for demonstration purposes

5. Energy performance testing, standards and labelling

Irrespective of the refrigerant used, split ACs should be designed for high energy efficiency and verified using the appropriate framework. This relates to energy efficiency performance metrics, minimum efficiency requirements, performance testing standards and labelling. The energy efficiency of split-type AC is rated and expressed as *Energy Efficiency Ratio* (EER) or *Seasonal Energy Efficiency Ratio* (SEER)[12]. They express the amount of cooling per unit of electrical energy drawn by the AC. The higher the ratio, the more efficient the appliance; for instance, more cooling is achieved for the same amount of electrical energy. Both are used as the basis for determining the (number, star or letter) rating in energy labels, which are placed on split ACs in various markets. Coverage of global mandatory AC energy performance standards doubled worldwide in the last 15 years.

Still, there is enormous remaining potential to reduce energy consumption. Globally over 40% of energy used for air conditioning can be saved by applying international best practice standards and an additional 20% by applying best available technologies.

Whereas the EER indicates the efficiency of a split AC at one predefined in- and outdoor temperature at full thermal load (therefore used for split ACs with a fixed-speed compressor), the SEER is calculated with the same indoor temperature, but across a range of outside temperatures over the course of a typical cooling season in full and part loads (mainly used for inverter split ACs). Determination of SEER involves defining annual temperature profiles and usage patterns, performance measurements at several part-load conditions, applying a weighting to each and then calculating the overall SEER. Thus, SEER standards have to account for different countries' conditions according to their distinct climate profile.

With many markets moving from fixed-speed split ACs to split ACs using a variable speed compressor driven by an inverter, a clear trend from EER to SEER can be observed in many countries. *Table 8* provides an overview of the fixed and seasonal performance measures and their features. Comparing the EER of one model to the SEER of another will not lead to conclusive results as the applied test conditions are different.

Ratio	Calculation and conversion	Testing standards
Energy Efficiency Ratio (EER)	The EER of a particular cooling device is the ratio of thermal cooling capacity to total input electrical energy (in W) at a given operating point. EER is generally calculated using a 35°C outside temperature (wet bulb temperature of 24°C) and an inside (return air) temperature of 27°C (wet bulb temperature of 19°C)	ISO 5151:2017 – Non-ducted ACs and heat pumps – Testing and rating for performance The ISO 5151 testing standard specifies how to measure the cooling capacity and efficiency of ACs using stipulated test conditions.
Seasonal Energy Efficiency Ratio (SEER), also known as Cooling Seasonal Performance Factor (CSPF)	The SEER is calculated with the same (27°C) indoor temperature, but over a range of out- side temperatures from 17°C to 40°C, with a certain specified percentage weighting of time in each of 24 bins spanning 1°C.	EN 14825: 2022 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling, commercial and process cooling – testing and rating at part load conditions and calculation of seasonal performance EN 14825:2022 specifies parameters and calculation methods for the determining the SEER and SEERon, as well as other specific parameters for cooling and heating efficienciesISO
Cooling Seasonal Performance (27°C) indoor temperature, but over a range of outside temperatures from	Factor (CSPF) 20°C to 35°C (Group1) and 21°C to 46°C (Group 2), with a certain specified	The CSPF is calculated with the same number of hours per 1°C temperature interval. ISO 5151:2017 – Non-ducted ACs and heat pumps – Testing and rating for performance ISO 16358-1:2013 Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 1: Cooling seasonal performance factor. ISO 16358-1:2013 specifies the test and calculation methods for the cooling seasonal performance factor of equipment covered by ISO 5151:2017. It allows for fixed speed and inverter ACs to be rated under the same metric and product category, capturing part-load savings from inverters, and provides flexibility in adoption of a country specific temperature bin (i.e. a representation of the country's year-round cooling demands).

Table 8: Overview of energy performance metrics and testing standards[13]

12 This table only covers a selection of common metrics and it does not aim to be complete.

13 Other terminology is in use for comparable measures. For example coefficient of performance (COP) and seasonal COP (SCOP) are sometimes use for heating performance of a refrigerating system. Other terms include Cooling Seasonal Performance Factor (CSPF), Heating Seasonal Performance Factor (HSPF), Annual Performance Factor (APF), Integrated Part Load Value (IPLV), Non-standard Part Load Value (NPLV); the latter two are normally applied to chaillers.

The Indian Seasonal Energy Efficiency Ratio (ISEER)

The *Bureau of Energy Efficiency* (BEE) has introduced the Indian SEER, known as ISEER, in 2015. This nationally adopted SEER takes into account local climate conditions. The methodology and test conditions follow the standard references ISO 16358-1: 2013 and the Indian standard for room ACs IS 1391 Part 1 and 2. ISEER measures energy efficiency of ACs based on a weighted average of the per- formance at different outside temperatures. The temperature profile is based on a bin temperature range of 24 to 43°C and 1600 operating hours per cooling per annum as illustrated in *Table 9*.

Temperature in °C	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	Total
Average Annual Hours	527	590	639	660	603	543	451	377	309	240	196	165	130	101	79	59	44	31	20	10	5,774
Fraction	9.1	10.2	11.1	11.4	10.4	9.4	7.8	6.5	5.4	4.2	3.4	2.9	2.3	1.7	1.4	1.0	0.8	0.5	0.3	0.2	100
Bin Hours	146	163	177	183	167	150	135	104	86	67	54	46	36	28	22	16	12	9	6	3	1,600

Table 9: Reference outdoor temperature bin distribution adapted from Indian Weather Data Handbook, 2014 (BEE, 2015)

For each bin between 24°C and 43°C, two measurements of cooling capacity and power consumption are taken at full and half load capacity. BEE (2015) provides an excel spreadsheet to calculate the final ISEER value. Furthermore, a related star rating plan was developed and has become mandatory in the beginning of 2018 (*refer to Subchapter 5.2*).

5.1. Minimum energy performance standards

Minimum Energy Performance Standards (MEPS) refer to mandatory energy efficiency performance requirements of regulated products in a country or region. In this context, MEPS for split ACs help to increase the efficiency of split ACs by introducing a minimum efficiency level obligatory for all models sold in a particular market/country. New split AC models introduced to a market subject to the predefined MEPS must meet a minimum efficiency ratio, which is tested according to the testing standards listed in *Table 8* and verified by an accredited testing laboratory. Models not meeting the minimum efficiency requirements may no longer be imported or sold after the effective date of implementation of the standard. Hereby, MEPS encourage manufacturers to improve the efficiency of their products or to innovate and develop more efficient technologies, when applied in conjunction with supporting policies. Before MEPS are adopted, cost-benefit analyses must be performed to ensure the associated regulatory measures provide economic benefits to consumers.

5.2. Energy labelling

Labelling is one of the most direct and effective instruments to deliver information about energy, cost, and environmental performance of split ACs to consumers. Labels are also an important basis for other supporting and financing instruments, such as education, financial incentives (rebates, grants), and financing (loans), as well as green public procurement.

There are, generally, three major groups of labels: endorsement, comparative, and informative. Comparative labels have two major subgroups, continuous comparative and categorical comparative.

These labels should be easy to understand and may be supplemented with additional user communication materials. An AC label could include information on EER or SEER, and refrigerants in use. Regular review of the market and of labelling tiers is important to ensure continued impact of the energy label.

References and relevant resources:	
Energy performance standards	• ISO 5151:2017 – Non-ducted air conditioner and heat pumps – Testing and rating for performance • ISO 16358-1:2013 Air-cooled air conditioner and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 1: Cooling seasonal performance factor. • ANSI/AHRI 210/240 2017, Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment
Guidance on test methods and efficiency calculation	• UN Environment – United for Efficiency (U4E 2019), Model Regulation Guidelines for Energy-Efficient and Climate-Friendly ACs | https://united4efficiency.org/wp-content/uploads/2019/09/U4E_AC_Model-Regulation_20190923.pdf
Guidance on designing MEPS and energy labelling	• UN Environment – U4E (2017), Accelerating the Global Adoption of Energy efficient and Climate-friendly ACs

The Indian energy labelling for room AC (comparative label)

With the objective of progressively improving the efficiency of cooling appliances and transforming market towards better energy efficiency standards, the BEE has revised its energy labelling of Room ACs. BEE applies a star energy labelling, which has been continuously tightened throughout the last decade so the 5-star levels in 2010 became 3-star in 2015 and will become 1-star in 2018 as per new ISEER methodology. The energy efficiency of ACs has increased by 25% from 2.6 in 2006 to 3.26 in 2015 due to tightening of standards.

Star Rating	Minimum ISEER	Maximum ISEER
1 Star	3.10	3.29
2 Star	3.30	3.49
3 Star	3.50	3.99
4 Star	4.00	4.49
5 Star	4.50	

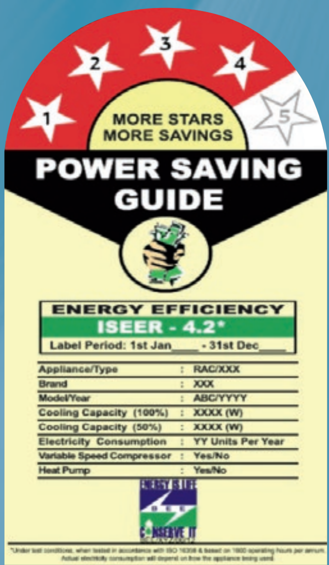


Figure 20: India's mandatory energy label and star rating, valid from 01/01/2018 until 31/12/2019 (BEE, 2015), 5-star label split AC with 5.8 ISEER and R290 refrigerant (Godrej , 2018b)

6. Ecolabelling of R290 room ACs

In addition to legally binding MEPS, voluntary ecolabels are an instrument to push the market towards a better environmental performance of products. Ecolabels predominantly address consumers in order to provide them with the information of environmental preferable products and services. This is to facilitate taking into account environmental concerns in purchasing decisions. Today, there is a plethora of different ecolabels for consumer goods with a majority being company or industry association labels which do not follow standardized procedures regarding the environmental assessment of a product and, thus, can be misleading for buyers. This chapter focuses on environmental labelling programs which have been established according to ISO 14024 "Environmental labels and declarations – Type I environmental labelling – Principles and procedures" and which have developed requirements for the certification of room ACs. For this reason, the U.S. Energy Star requirements for room AC are not considered. In contrast to other ecolabels for ACs, Energy Star exclusively addresses energy efficiency aspects and does not consider the refrigerant.

ISO 14024 ecolabels are voluntary labels which can be operated by public, or private agencies at the national, regional or international level. Products are certified as a result of a third-party verification process of environmental requirements (often referred to as "criteria"), which are based on life-cycle considerations of the product. It is very important not only for the ISO 14024 certification, but also for the credibility of a labelling program that the certification requirements are established independently in a transparent procedure and build on scientific findings. A life cycle impact assessment (LCIA) carried out in a study prior to the establishment of the German ecolabel showed that electricity consumption related to operating ACs causes by far the greatest environmental impacts in all assessed categories such as GHG emissions, terrestrial acidification, and freshwater eutrophication (see *Figure 21*) (UBA, 2018). The use of R410A, which is the standard refrigerant in AC and exhibits a GWP of 1,924, also caused a considerable contribution to GHG emissions (roughly 20%) (Myhre et al., 2013).

LCIA of product A with R410a

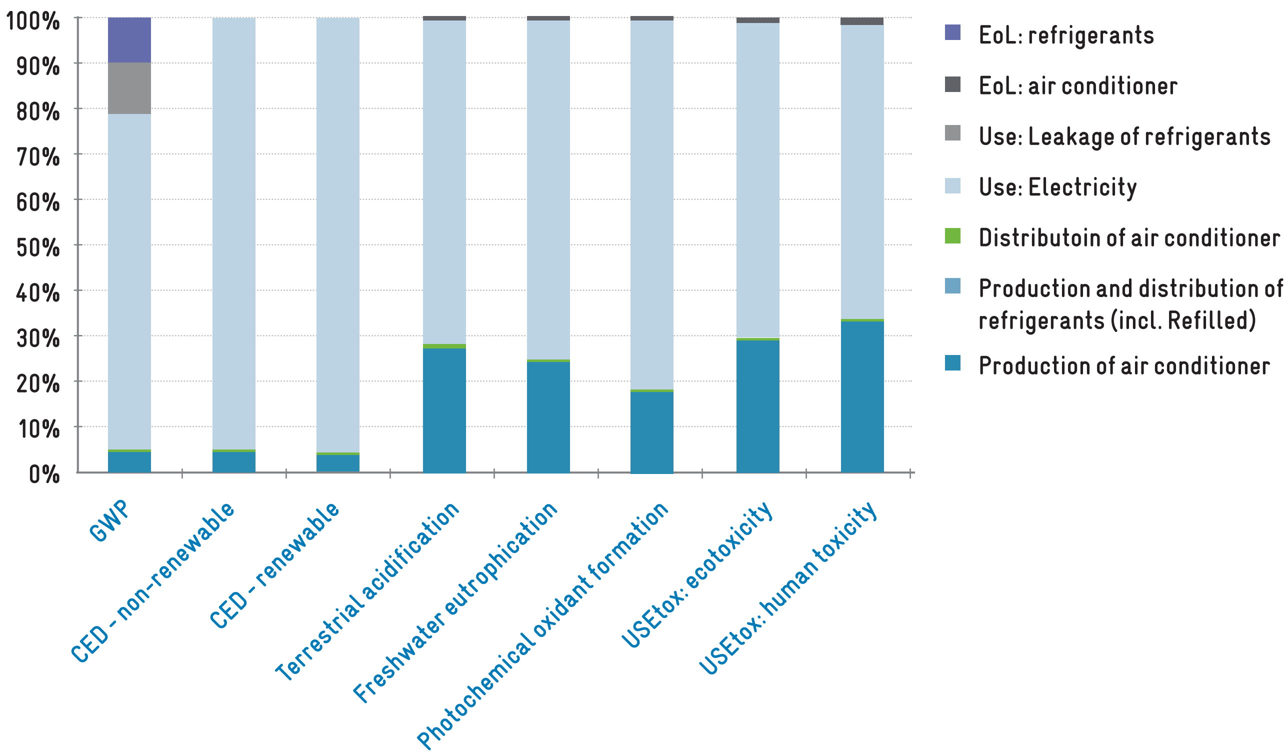


Figure 21: Life cycle impact assessment of a single-split AC using R410A as the refrigerant (UBA, 2018)

Another assessment was carried out for a split AC with a nominal cooling capacity of 5 kW, using various alternative refrigerants (GIZ, 2022[14]). *Figure 22* shows the CO_2-eq emissions, including both production (for the refrigerant and construction materials) and the in-use/end-of-life (EOL) refrigerant emissions; contribution of lifetime energy consumption is not included because (a) values are assumed equal for all refrigerants since the AC will be designed to meet a given energy efficiency label and (b) CO_2 emissions factor (per kWh) of electrical energy consumed varies widely around the world so any value would be unrepresentative of any other given country. The two columns reflect the calculations using both 100-year and 20-year integration time horizon for the refrigerant GWP. Estimations of material costs (such as necessary heat exchanger sizes) to construct the split AC to achieve equal seasonal efficiency, as well as the cost of safety measures where applicable, are shown in *Figure 23*. One column reflects material costs only (metals, plastics, additional safety-related components), whereas the other column includes the lifetime cost of refrigerant as well.

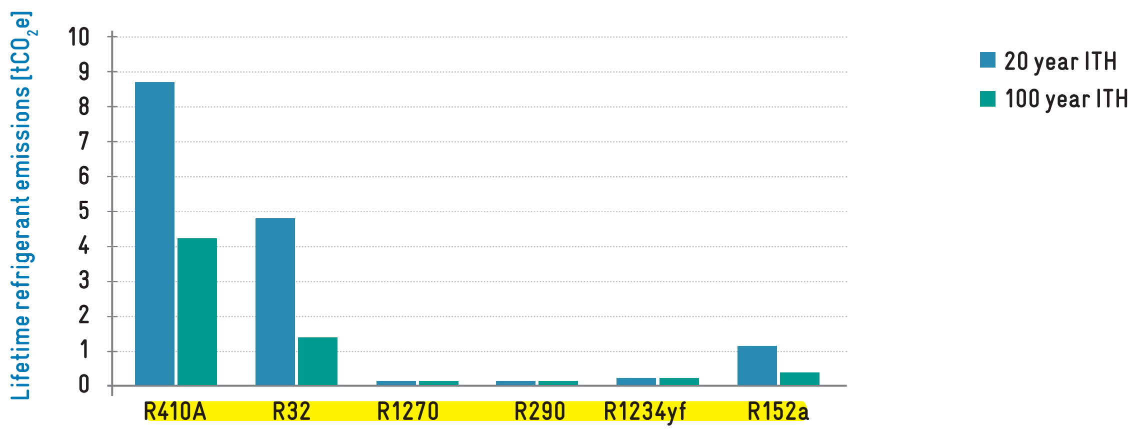


Figure 22: Total lifetime refrigerant emissions (including production and in-use stages) of split AC for several alternative refrigerants

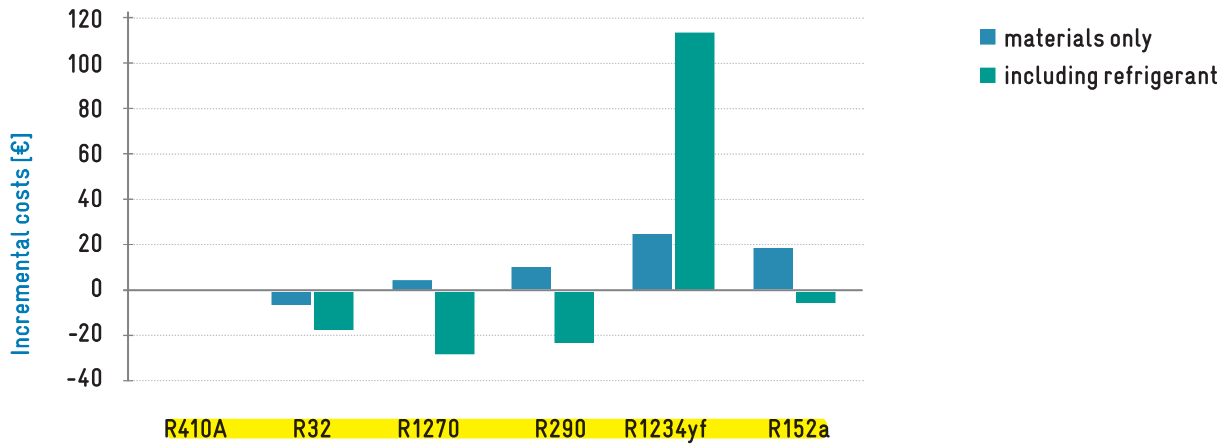


Figure 23: Incremental material costs of the split AC, relative to R410A with several alternative refrigerants

14 GIZ Proklima (2022). https://www.green-cooling-initiative.org/news-media/publications/publication-detail/2022/10/05/can-refrigerants-with-a-gwp-below-150-be-used-for-split-air-conditioners-in-europe

Ecolabel criteria for room ACs have been established in China, South Korea, Thailand, Scandinavia[15] (termed “air- air heat pump”), and Germany as part of the national (multinational in the case of Scandinavia) ecolabel programs. *Table 9* provides an overview of the current (multi-) national ecolabels for room ACs and their basic criteria. The focus lies on the requirements regarding energy efficiency and the refrigerant. In addition, much attention in all label requirements is given to the noise emitted by the indoor and outdoor unit of a split AC system.

Ecolabel		China Environm. Labelling	Korea Eco-Label	Green Label Thailand	Blue Angel
Country/Region		China	South Korea	Thailand	Germany
Latest Version		2013	2013	2016	2016
Selection of Requirements	Energy Efficiency[16]	Range from: SEER≥5.4 (Seasonal Coefficient of Performance (SCOP)≥4.5) for units <4.5 kW SEER≥4.7 (SCOP≥3.7) for units with 7.1 to 14 kW	fulfill first class Energy Efficiency Rating, according to the efficiency management equipment operation regulations	EER>2.82 Based on Thai Industrial Standard TIS 2134: Room ACs: Energy Efficiency (EGAT Label No. 5 requirements)	SEER≥7 SCOP≥4.6
	Refrigerant	Ozone Depleting Potential (ODP)=0 No GWP limit	ODP=0 GWP≤2,500	ODP=0 GWP≤2,500	halogen-free, ODP=0 GWP<10
	Noise Level[17]	Sound Pressure Limits Cooling Capacity (CC) <2.5 kW IDU: 39 dB(A) ODU: 40 dB(A)	CC < 4kW IDU: 45 dB(A) ODU: 55 dB(A) 4kW≤CC<10 kW IDU: 50 dB(A) ODU: 60 dB(A)	Sound Pressure Limits CC <8 kW IDU: 50 dB(A) ODU: 57 dB(A	Sound Power Limits CC ≤4.5 kW IDU: 50 dB(A) ODU: 58 dB(A) 4.5 kW<CC≤6 kW IDU: 55 dB(A) ODU: 62 dB(A)
Reference		China Environmental United Certification Center (CEC); UBA (2018)	Ecolabel Standard EL401: Air ConditionersKorea Ecolabel Standard EL401: ACs	Green Label Product Room AC (TGL-7-R3-14)	Blue Angel, The German Ecolabel: Stationary ACs DE-UZ 204

Table 10: Overview of ISO 14024 ecolabels for split ACs

References and relevant resources:	
Blue Angel Criteria and comparison to other ISO 14024 ecolabels	• UBA (2018), The Blue Angel for Stationary Room Air Conditioners – market analysis, technical developments and regulatory framework for criteria development

15 The Nordic Swan ecolabel was established by the Scandinavian countries Denmark, Finland, Iceland, Norway and Sweden in 1989.

16 SEER values across countries cannot be directly compared due to different test conditions.

17 Direct comparison of noise emission limits between European and Asian labels is not fully possible due to the different measuring methods (sound power level vs. sound pressure level respectively). As a rule of thumb, the sound power level is around 8-10 dB higher than the sound pressure level.

New environmental-friendly and low GWP label for room ACs in China

In 2015, *China Household Electrical Appliances Association* (CHEAA), *Foreign Economic Cooperation Office* (FECO) of the Ministry of Environmental Protection, *United Nations Industrial Development Organization* (UNIDO), UNEP and GIZ released an ecolabel for room ACs and Heat Pump Water Heater (HPWH) products regulated under the National Standards GB/T 7725 and GB/T 23137 respectively (CHEAA, 2015). Although it is not certified as ISO 14024 ecolabel, unlike the CEC label, it calls for a GWP limit for the refrigerant lower than 150. The energy efficiency levels are slightly below the CEC definition. The label does not cover noise level, materials, and other requirements.

After a voluntary application at the management office, *China Compulsory Certification* (CCC), test reports, energy efficiency reports, and other relevant documents are examined and verified. With the approval, the applicant is allowed to use the label on the qualified products free of charge. Up to date four companies including Haier, Midea, Gree, and Changhong with eleven R290 split AC products are authorized to use this ecolabel.

Blue Angel certification of Midea hydrocarbon-Inverter split AC

Despite the fact that currently there is no single-split AC using halogen-free refrigerant on the market in Germany, the Chinese company Midea applied for certification of two units with capacities of 9,000 BTU/h (2.6 kW) and 12,000 BTU/h (3.5 kW) (Blue Angel, 2018a). It was approved in February 2018 (Blue Angel, 2018b) being the first split AC to receive the Blue Angel ecolabel. *Figure 26* (below) illustrates the procedure that needs to be accomplished in order to obtain the German ecolabel certificate.[20]

Figure 24: Formal procedure for Blue Angel certification

SUPPLIERS SUBMIT THEIR APPLICATION in order to use the environmental label, verification of compliance with the requirements is sent to the awarding body RAL

CHECK OF THE APPLICATION for the use of the environmental label for compliance with the requirements by RAL

FEDERAL STATE submits statement

CONCLUSION of the contract on the use of the environmental label with the supplier/manufacturer by RAL

ADVERTISING BY THE SUPPLIER using the environmental label based on the contract on the use of the environmental label concluded with RAL

20 The third party verification process of the compliance with the requirements of a certain product group is carried out by RAL gGmbH (https://www.ral.de/en/).

INTRODUCING SUSTAINABLE AIR CONDITIONING TO TECHNICIAN TRAINERS IN THE PHILIPPINES

The demand for space cooling in the Philippines is growing rapidly due to higher ambient temperatures, a rising middle class, as well as the economic and demographic growth. The country's space cooling is currently characterized by its use of low-efficiency ACs with highly climate damaging refrigerants. Without interventions and transition to more energy-efficient appliances and reduction of high-GWP refrigerants and leakages, it is assumed that the RAC sector could account for 13% of global GHG emissions by 2030. In cooperation with the Philippines' Technical Education and Skills Development Authority (TESDA), the Cool Contributions fighting Climate Change (C4) Project has been running a series of train-the-trainer sessions for 32 RAC training professionals covering the proper use of highly efficient R290 split ACs. As a next step, these RAC trainers will cascade what they have learned to their students in TESDA training centers throughout the archipelago. This two-stage training process will lay the ground for the further development of the market for clean and efficient space cooling in the Philippines.

More information on climate-friendly AC can be found on: https://www.international-climate-initiative.com/en/iki-media/news/climate_friendly_air_conditioning_in_the_philippines

"Having introduced the training module on proper installation and servicing of R290 Air Conditioners to AC technician lecturers throughout the country is an important step in the urgently needed transition to green and efficient cooling technologies."

Dr. Elmar Talavera, Executive Director, Technical Educational Skills Development Authority Philippines

7. Installation and servicing of split ACs with flammable refrigerant

All uses of existing and new technologies entail risks that need to be managed. Given the flammability of hydrocarbons, proper and safe handling is of utmost importance in the process of manufacturing, installing, servicing, and repairing R290 split ACs.

Furthermore, proper installation and servicing of split AC units can benefit the efficiency and reliability of the equipment considerably over its lifetime, while avoiding additional costs for electricity and spare parts. At the same time, it reduces safety risks by avoiding problems before they even occur or detecting issues in an early stage to prevent accidents.

There is now an international standard, ISO 22712: 2023 Refrigerating systems and heat pumps – Competence of personnel, which provides guidance on the skills and knowledge that technicians, designers and other practitioners require. Specifically within IEC 60335-2-40: 2022, Annex DD provides an extensive list of instructions for technicians to follow when working on ACs.

Technician charging training unit during R290 split AC training at TESDA
© GIZ Proklima/ June B. Oliveros II

Regular and high-quality service and maintenance of split ACs not only ensure the safe and efficient operation of the equipment but also carry several economic benefits for the user (TEAP, 2022):

- Reduced refrigerant leaks
- Improved safety
- Better temperature control and thermal comfort for occupants
- Improved occupant productivity by reliably maintaining the indoor temperature
- Deferred capital expenditure for replacement and repair cost by extending the product lifetime

Further, the TEAP report states several measures for the improvement of servicing and maintenance practices

- Training and education of service technicians, system operators with view to handling new refrigerants.
- Certification and registration of technicians, installation and servicing companies and other entities on handling of refrigerants.
- Policies to encourage regular maintenance and servicing (i.e. maintenance contracts or warranties could be included as part of government procurement).
- Ensure that technicians are equipped with minimum set of necessary tools to use flammable refrigerants.

7.1. Installation

Manufacturers' installation and operation manuals must explicitly state the conditions for a safe installation of the split AC equipment. Technician must follow these prescribed conditions.

The installation of a R290 single-split AC requires the technician to undertake a set of precautionary steps in addition to the proper installation of a conventional split AC, which are summarised in the following:

Room size and location of IDU and ODU

The technician must start with ensuring that the required minimum room size is met. The room size depends on the amount of R290 charge in the refrigerant circuit of the appliance as well as the installation height of the IDU (refer to *Chapter 4.1*).

This allowable charge size and minimum room area is typically based on the assumption that under the worst-case leak situation, the entire refrigerant charge from a system can leak into a space almost instantaneously; since the vapour is denser than air, it will partially stratify, meaning the concentration will be the highest at floor level. Therefore, the amount of refrigerant is limited so that under these circumstances the concentration of refrigerant will be lower than the LFL and therefore a flammable mixture cannot be formed. Further, the ODU requires minimum separation distances from the wall and other surrounding objects.

Potential ignition sources

The appliance shall be installed in a room without continuously operating ignition sources at or close to floor level (e.g. open flames such as a gas oven or stove).

Piping

The IDU-to-ODU flared pipe connection must be placed outside of the air-conditioned room (occupied space). Alternatively, a permanently technical tight connection can be established (pipe joining by brazing or the use of press-fittings). Maximum pipe length to be installed according to the manufacturer's specification.

Electrical installation

Electrical installation for the AC equipment must be executed according to the local technical connection requirements, issued by the responsible energy supply company and according to applicable standards and regulations. One important factor is that all equipment must be electrically grounded. Each unit must have a separate electrical circuit breaker (fuse).

Charging with refrigerant

The split AC system must be charged with the maximum allowable refrigerant charge amount only, prescribed and indicated (system label) by the manufacturer. Topping-up the system with refrigerant is prohibited for installation and servicing activities

Tools

During installation and maintenance, all tools and equipment should be appropriate and used appropriately for R290. Tools and equipment that could arc/spark in normal use must be placed beyond the anticipated "flammable zone" – typically three metres from locations of possible releases. Non-sparking equipment and tools should be used wherever applicable. For example, if the vacuum pump is not an Ex-type, it should be switched ON and OFF by putting in the plug into the socket. Plug and socket are placed beyond a two metre safety zone.

Labelling

Ensure that warning stickers are visible at the IDU and ODU when refrigerant-containing parts are accessed.

7.2. Servicing and repair

Service and maintenance are critical for safe and reliable operation of air conditioners. In absence of regular service and maintenance the safety status and performance drops significantly. If the service and maintenance of the AC system is properly done, its performance will be maintained and will surely benefit the end user in terms of energy and repair costs. Moreover, the probability of a service breakdown is also reduced.

A basic maintenance includes:

- Cleaning the fins and the unit with blower; safe guarding the fins
- Checking and cleaning of blower and propeller fan
- Checking various electrical components, wiring & thermostat.

System repairs may include accessing a system, either to add refrigerant or remove it, service valves should be employed. Under no circumstances must the system be broken into if it contains any flammable refrigerant or any other gas under pressure, by means of cutting or breaking pipe work.

The following procedure is recommended (GIZ Proklima, 2013):

- Conducting a hazard analysis and risk assessment for the proposed repair
- Electrically isolate the system
- Recovering refrigerant from the sealed refrigeration system
- Repairing/replacing inoperative spare parts
- Cleaning/polishing and flushing the system
- Careful brazing and/or flaring of tubes
- Leak and pressure testing
- Evacuation and vacuum holding
- Refrigerant charging
- Sealing the process tube and closing the valves
- Routine checking for proper operation
- Recording the details of work done.

Safety work area and temporary flammability zones

When working on systems using flammable refrigerants, the technician should consider certain locations as "temporary flammable zones". These are normally regions where at least some emission of refrigerant is anticipated to occur during the normal working procedures, such as recovery, charging and evacuation, typically where hoses may be connected or disconnected. The technician should ensure three metres safety working area (radius of the ODU) in case of any accidental release of refrigerant that forms a flammable mixture with air. The drawing below indicates the arrangement of equipment and tools for service work where flammable refrigerant can be present (Godrej, 2018d).

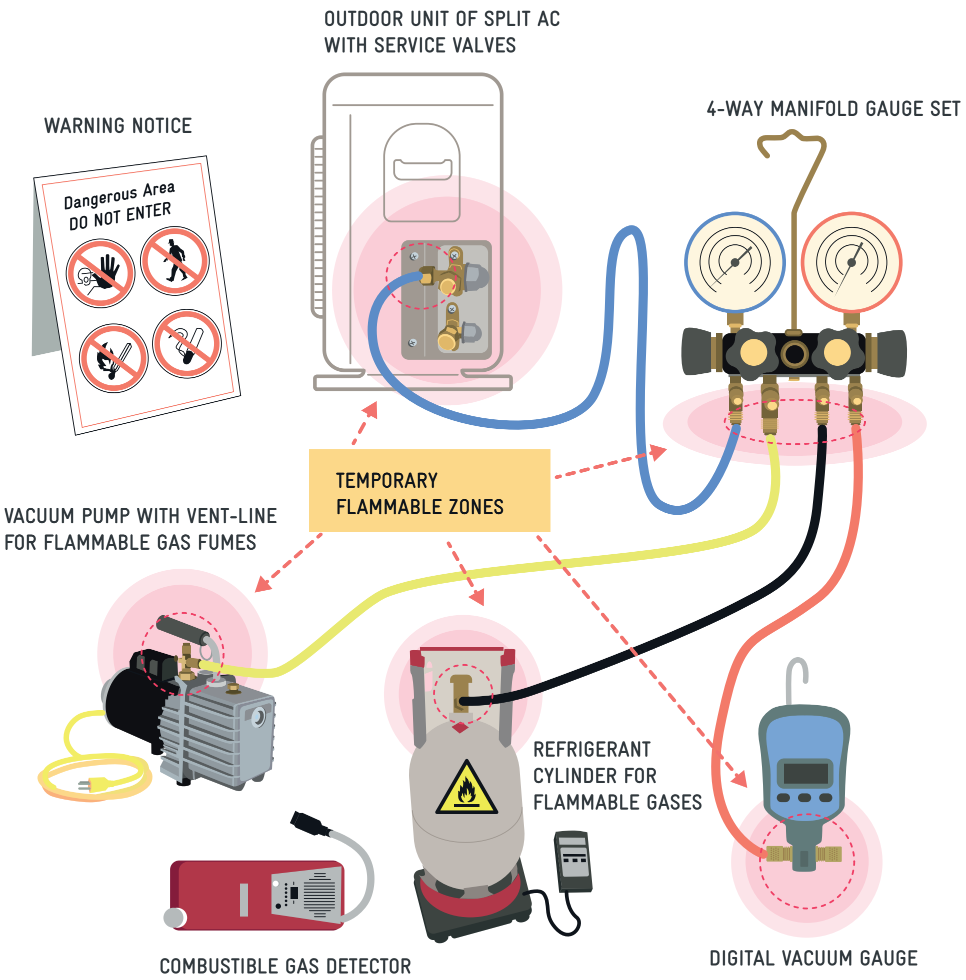


Figure 25: Arrangement of tools and potential temporary flammability zones adapted from Godrej/Hühren, 2018d

7.3. Decommissioning and disposal

When replacing a split AC using R22, R410A or R32 refrigerant with a R290 split AC, it is strongly recommended to recover the refrigerant in an appropriate recovery cylinder and send to destruction or reclamation in order to avoid the massive climate impact that results from releasing HCFC or HFC refrigerants into the atmosphere. GIZ Proklima (2013) describes different recovery methods in detail and provides further information about recycling and reclamation of split AC refrigerants.

Given its negligible global warming impact, releasing R290 into the atmosphere is significantly less harmful to the climate. Under most circumstances, it is acceptable to vent the R290 refrigerant. However, due to its flammability, it is essential to follow the appropriate safety procedure which is elaborated in detail in Chapter 5.3.3. of the Godrej 'Technician Training Manual for Split Air Conditioners with R290 refrigerant'.

7.4. Qualification, certification, and registration of AC technicians

In many countries, the installation, servicing, and repair of split ACs is characterised to a large extend by informal practices. Often, people without any or little formal RAC qualification and certification install and service the equipment, leading to leakages and inefficient operation. Consequently, a formalised *qualification, certification, and registration* (QCR) infrastructure based on product standards is essential in order to treat R290 split ACs in a safe, energy-efficient, and environmentally sound way. The following points need to be addressed, when establishing a QCR infrastructure (*see Figure 28*):

In addition to EN 378 and ISO 5149, which applies to technicians who carry out work on self-contained refrigerating systems, ISO22712 defines levels of competence expected across a range of different RAC activities and serves as the normative backbone for the qualification and certification of RAC technicians who install and repair split AC systems. Close coordination between the split AC industry, government, and related national standardization and educational bodies is required to establish a QCR infrastructure for AC technicians in compliance with these or nationally adopted standards.

Qualification	Certification	Registration
• Identify local Qualification-partners • Assess existing education and skill levels • Assess compliance with relevant national /international standards • Benchmarking existing Code of Practice • Define entry and examination levels • Pre-entry level support • Adapt materials • Conduct ToT + assist implementation • Develop test procedures	• Identify local certification-partners • Identify certification needs of people, companies, products • Develop examination procedures • Build capacity of certification bodies • Develop materials, tools and instruments • Assist labelling, monitoring, and reporting	• Partner with registration body • Assess local procedures • Identify registration needs people, companies, products • Develop registration scheme and enforcement required • Assist development of materials, tools + instruments • Assist reporting + monitoring

Figure 26: Important steps to establish QCR infrastructure based on HEAT (2017)

References and relevant resources:	
Competence of personnel / training standards	• EN 13313: 2011 – Refrigerating systems and heat pumps. Competence of personnel
Guidance on safe handling of flammable refrigerants	• GIZ Proklima & TÜV Süd (2010), Guidelines for the safe use of hydrocarbon refrigerant
Split AC installation and servicing Manuals	• GIZ Proklima (2013), Good Practices in Installation and Servicing of Room Air-conditioners, RAC Technicians Handbook • Godrej & Boyce Training Manual for Godrej Split Air-Conditioners with Hydrocarbons (R290 Refrigerant) (available upon request) • Midea Installation and Service Manual (available upon request)
Recovery, Recycling and Reclamation of Refrigerants	• GIZ Proklima (2013), Good Practices in Installation and Servicing of Room Air-conditioners, RAC Technicians Handbook, Chapter 9
Installation Report of R290 split AC	• DMT (2018), Report according to the installation of a split type room air conditioner with R290 (available upon request)

Godrej's AC technicians training and certification system

In accordance with the QCR approach, Godrej & Boyce India has established an AC technician training and certification network, which allows the company to fully capture and control the installation, servicing, and repair of R290 split ACs.

Qualification:

- 5 head trainers (trained by a team of Godrej and GIZ) and 18 branch trainers carry out a 6 day-training courses on safe installation, servicing, and repair of R290 split ACs on a regular basis (once every quarter).
- The trainings follow a comprehensive training manual, knowledge updates are disseminated to all Godrej technicians.
- These branch trainers either operate in two company-owned or 30 collaborating independent training institutes.
- Of these, Godrej equipped 12 centres with tools for the introduction of and training with new models. Godrej either trains experienced technicians proposed by (multi-brand) service providers or graduated technicians coming from high schools. All technicians undergo refreshment trainings once a year.
- So far, Godrej maintain a pool of approx. 5,000 qualified and certified R290 split AC technicians

Certification:

- Godrej maintains a self-certification system in line with the national certification policies. Only certified technicians are permitted to install and service R290 split ACs.

Registration:

- Godrej maintains an online system to manage their AC technician network.
- Each Godrej AC technician receives a unique identity code after accomplishment of training and certification, which allows tracking of the installation and servicing of every single unit and its attribution to the responsible technician.
- After purchase (either in the internet or at other points of sale), the online system chooses the technician team who installs and services the appliance based on availability and proximity to installation site, always with the aim to install on the day of purchase. Installation is always carried out by a team of two technicians.
- After installation, the customer receives the complete satisfaction number (CSN) which enables the customer to rate the service offered through a unique code. By default, each costumer will receive three service requests throughout the first year after installation, with one service free of charge during the first year. It is recommended that servicing is done through company trained technicians only. After the first year, a maintenance contract for once a year servicing is offered and proposed in the user manual.
- Registered Godrej technicians (always a team of two) are able to service up to six split ACs units per day. Usual servicing includes cleaning of the IDU and ODU there may also be minor repairs in case the customer complains of water dripping or noise issues.

"We do the training and certification of AC technicians ourselves, we take full responsibility. Thereby, we ensure a well-functioning work force in the field."

Shakeel M. Jamadar, Dy. General Manager -
Head of Service Training, Godrej Appliances India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