TEXTE
22/2018

The Blue Angel for Stationary Room Air Conditioners – market analysis, technical developments and regulatory framework for criteria development

Background Report

For our Environment

Umwelt Bundesamt

TEXTE 22/2018

Environmental Research of the
Federal Ministry for the
Environment, Nature Conservation,
Building and Nuclear Safety

Project No. (FKZ) 3714 95 3060

The Blue Angel for Stationary Room Air Conditioners – market analysis, technical developments and regulatory framework for criteria development

Background Report

by

Tobias Schleicher, Ran Liu, Jens Gröger
Öko-Institut e.V., Freiburg i.Br.

Jonathan Heubes, Pascal Radermacher
HEAT GmbH, Königstein

On behalf of the German Environment Agency

Imprint

Publisher:
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
info@umweltbundesamt.de
Internet: www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt

Study performed by:
Öko-Institut e.V.
Merzhauserstr.173
79100 Freiburg i.Br.

HEAT GmbH
Seilerbahnweg 14
61462 Königstein

Study completed in:
June 2017

Edited by:
Section III 1.6 Product Responsibility
Dr. Ines Oehme
III 1.4 Substance-related Product Issues
Dr. Daniel De Graaf

Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4804

Dessau-Roßlau, March 2018

The project underlying this report was financed by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear safety under project number FKZ 3714 95 3060. The responsibility for the content of this publication lies with the author(s).

Abstract

The purpose of this study is to analyse the technical, economic, legislative and environmental background of the product group room air conditioners in order to derive award criteria for the German ecolabel "The Blue Angel" including international cooperation activities with China, Thailand, India and South Korea. Besides a first focus on the definition and scope of the product group, it provides a comprehensive market overview looking into the global demand and supply situation as well as the detailed picture of the above mentioned countries. The results show that Germany's relatively small market for air conditioners is characterised by an almost complete import situation. On the other hand, this is reflected by large exports by countries like China and Thailand.

The analysis of the technology trends mostly focusses on the use of refrigerants and energy efficiency. Currently various trends are observed: European countries focus on natural refrigerants (e.g. hydrocarbons) with a global warming potential (GWP) ≤ 5 while some Asian countries focus on the refrigerant R-32 (GWP 675). Furthermore, this study shows that air conditioners operating with R-290 (Propane) can reach a seasonal energy efficiency ratio (SEER) of 7 under the current European standards.

The comparative Life Cycle Assessment (LCA) of this study shows that single-split air conditioners operating in a moderate climate zone that make use of natural refrigerants such as R-290 can typically save up to 30% Greenhouse Gas Emissions as compared to devices that use conventional hydrofluorocarbons) HFCs such as R-410A. In tropical climate zones this GHG saving typically amounts up to almost 50%.

The study closes with the derivation of award criteria for the Blue Angel ecolabel.

Kurzbeschreibung

Diese Studie untersucht den wissenschaftlich-technischen, ökonomischen, gesetzlichen und umweltrelevanten Hintergrund der Produktgruppe Raumklimageräte mit dem Ziel, Vergabekriterien für das Umweltzeichen „Der Blaue Engel" abzuleiten. Darüber hinaus sollen die Ergebnisse Eingang in die internationale Zusammenarbeit des deutschen Umweltzeichenprogramms mit den Ländern China, Thailand, Indien und Süd-Korea finden.

Neben Fragen zur Abgrenzung der Produktgruppe, liegt der Schwerpunkt zunächst auf einer umfassenden globalen Marktanalyse, welche durch vertiefte Länderstudien zu den oben genannten Ländern ergänzt wird. Sie zeigen beispielsweise, dass der relativ kleine Importmarkt für Klimageräte in Deutschland großen Exportüberschüssen von Ländern wie China und Thailand gegenübersteht.

Der Schwerpunkt der Technologieanalyse liegt auf den eingesetzten Kältemitteln sowie der Energieeffizienz. Hier können unterschiedliche Trends identifiziert werden: während sich die Europäischen Länder auf den Einsatz natürlicher Kältemittel mit einem Treibhausgaspotential (GWP) ≤ 5 fokussieren wollen, geht der aktuelle Trend in manchen asiatischen Ländern in Richtung R-32 (GWP=675). Des Weiteren zeigt die Analyse, dass unter den aktuell geltenden Europäischen Normen Raumklimageräte, welche Propan (R-290) als Kältemittel verwenden, eine Energieeffizienz entsprechend eines Jahreszeitabhängigen Energieeffizient SEER=7 erreichen können.

Die vergleichende Ökobilanz zeigt, dass Raumklimageräte, welche in einer moderaten Klimazone betrieben werden und natürliche Kältemittel wie Propan (R-290) verwenden gegenüber Anlagen mit konventionellen Kältemitteln wie R-410A über den gesamten Lebenszyklus Treibhausgasemissionen in Höhe von 30% einsparen können. Werden die Anlagen in einer tropischen Klimazone betrieben erhöht sich diese Treibhausgaseinsparung auf fast 50%.

Die Studie schließt mit der Ableitung von Kriterien für das Umweltzeichen „Der Blaue Engel".

Content

Summary

The German Federal Ministry for the Environment together with the Federal Environment Agency has commissioned the research project "Development of the Ecolabel The Blue Angel for Air Conditioners and Compatibility with International Ecolabels". Within the areas of climate protection and eco-labelling, the project focuses on the product group single-split air conditioners.

This scientific, technical background report allows the derivation of award criteria for the ecolabel "The Blue Angel" (Der Blaue Engel) concerning single-split air conditioners.

Background

Air conditioning systems are increasingly used worldwide to create comfort temperatures in residential and commercial buildings, but also to guarantee an optimal human performance at office work. The global market covers around 105 million (2014) sold air conditioners per year with growth rates of 10-15% in many countries. The widespread use of air conditioners has a negative environmental impact: The refrigerant emissions due to leakage (direct emissions) and emissions from the energy consumption (indirect emissions) contribute to global warming. This is even though environmental friendly alternatives are available.

Various international agreements and regional or national policy instruments are already implemented to reduce these negative environmental impacts. The Montreal Protocol has been effectively controlling the use of ozone depleting refrigerants, such as Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) since 1989. Climate relevant HFCs, which were widely introduced as alternatives to ozone depleting substances, are listed under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Hydrofluorocarbons (HFCs) have recently been included in the Montreal Protocol by the historic Kigali amendment, aiming for a global phase-down of HFC. Besides, the European Union and various countries have formulated laws restricting the use of HFC, and have introduced energy labelling schemes and Minimum Energy Performance Standards (MEPS) to reduce energy consumption from air conditioners.

The ecolabel "The Blue Angel" offers another policy instrument to shift the market towards environmentally friendly products and increased sustainability. Many Asian countries have already established ecolabels for air conditioners.

This study analyses major markets, technology trends and the current regulatory framework. A Life Cycle Assessment (LCA) analyses the environmental impacts of using environmentally friendly air conditioners, while a Life-Cycle Cost (LCC) analysis shows the overall economic impacts. Finally, existing Asian ecolabels are compared. This information allows following the overall methodological structure of the Product Sustainability Assessment (PROSA) approach developed by Oeko-Institut e.V. (Grießhammer et al. 2007) which is used to derive award criteria for the Blue Angel.

In general, PROSA is a method for the strategic analysis and evaluation of product portfolios, products and services. Hence, it spans complete product life cycles and value chains; it assesses and evaluates the environmental, economic and (if possible) social opportunities and risks of future development trajectories. PROSA is a process-driven and iterative methodology which gives due regards to time and cost restrictions. It calls as far as possible on existing, well-established individual tools (Megatrend Analysis, Life-Cycle Assessment, Life-Cycle Costing etc.). Already in the past, PROSA has been used to derive eco-label criteria for numerous product groups for the Blue Angel in the past (Groeger et al. 2013). For more information on the methodological framework see chapter 2.

In general, there is a great variety of different room air conditioning systems. However, the systems can roughly be classified in three groups depending on the placement of the indoor unit (evaporator), the outdoor unit (condenser) as well as the number of indoor units: (1) Single packaged air conditioners, (2) Single-split air conditioners and (3) Multi-split air conditioners and variable refrigerant flow (VRF) systems.

The product group of interest within this project is single-split air conditioners. Here, the evaporator is located inside the building that is to be cooled or heated, whereas the condenser is outside the building. Both components are connected via piping. These types of systems are used in both the residential and the commercial sector. The primary function of single-split air conditioners is cooling, heating, or both. Devices that are capable of both cooling and heating are so-called reversible systems. In contrast to cooling-only devices, heating-only devices are not considered for the ecolabel. Possible secondary functions are the control of ventilation, humidity and air purity. For a detailed definition of the considered product group, this report refers to the Regulation (EU) No 626/2011 (Art. 2), however, excluding double duct air conditioners' and 'single duct air conditioners'.

The air conditioning market

The market size for residential and commercial air conditioners is around 105 m (million) units sold per year (2014). The market value surpasses US-$ 95 billion (2014). Major markets are found in Asia/Southeast Asia, with China as the most important market globally, followed by the Americas. Split systems (ductless and ducted) have the largest share of the global air conditioner market (> 85 m units sold per year in 2014). In particular, ductless single-splits – the focal group of the Blue Angel – clearly dominate the global market, especially in the Asian and Southeast Asian countries. Globally, single-split air conditioners have much higher market shares than single packaged air conditioners. However, this varies in some countries, e.g. in Germany with equal shares.

- The **Asian/Southeast Asian** economies do not only represent the world's largest consumers but also maintain the world's largest manufacturing capacities for air conditioning appliances (e.g. China, Thailand and India). Particularly, China and Thailand contribute to exports. The export of equipment must meet the requirements of the different target markets. This implies that several production lines can be in place locally, each designated to produce for specific markets, including the domestic market. The demand for air conditioners in Asia/Southeast Asian is around 65 m units per year (2014), with the highest demand in China. Apart from India and the Philippines, single-split air conditioners clearly dominate the market. Many of these tropical countries use air conditioners with cooling function only.
- **Europe** has an air conditioning market of around 6 m units sold per year (2014). Dominating markets are found in Russia (26%), Turkey and Italy (both 14%). Other markets in Europe are fairly small (< 10%). The most popular product group is split-air conditioners. The German air conditioner market is relatively small with roughly 190 k (thousand) units sold per year (2014). Almost all units are imported. Single-split air conditioners contribute to this demand with around 70-80 k units (mostly reversible units). Self-contained air conditioners (movable units) have similar sales volumes and are thus equally important. In Germany, centralised air conditioning solutions are common, e.g. chiller or VRF-systems. The current penetration of air conditioning in households is comparatively small (< 5%), however, a strong increase of sales figures is projected, stock figures of around 2.8 m units are expected by 2040. The systems exclusively use HFC and partly show high energy efficiency (e.g. Seasonal Energy Efficiency Ratio (SEER) up to 10).
- **Chinese** import figures are negligible. Within the country, the highest demand for air conditioners is found in the Eastern urban areas. On average, about 50% of Chinese households have residential air conditioning (20-25% in rural areas), which is one of the highest air conditioner penetration rate of Asia's emerging markets. Preferred air conditioner types are split systems (single- and multi-splits) with cooling capacities below 5 kW. The majority of sold room air conditioners include a

heat pump function, because they are typically not much more expensive than those with cooling-only function. Room air conditioners with energy-efficient inverter technology currently contribute around 50% to the annual sales figures and this share is expected to grow. Leading manufacturers are Gree, Midea and Haier with a combined market share of approx. 60%. The efficiency level of the units in the cooling mode reaches an SEER value of 5. Furthermore, Gree, Midea and Haier plan to introduce hydrocarbon-based single-split air conditioners with the support of the Multilateral Fund (MLF) of the Montreal Protocol.

- The **Indian** air conditioner market has not reached its expected potential in the past, even though sales figures almost tripled within the last 10 years. Currently around 3 m single splits are sold on the domestic market per year and 0.5 m units are imported and exported (2014). Single-split air conditioners have continuously gained market share in the past, exceeding the share of window-types now. In comparison to other countries, generally, air conditioners are relatively cheap in India. Hence, Indian consumers are sensitive regarding investment costs. The penetration rate in households is fairly low with less than 5% while cooling-only units dominate the market. However, the reversible systems are slowly picking up growth in the North of India. While in 2008 mostly units with larger cooling capacities (> 5 kW) were sold, this situation has changed in the meanwhile. Inverter air conditioners are still of minor importance but show significant growth rates with 25%. The efficiency range of the cooling units in India is between Energy Efficiency Ratio (EER) values of 3 and 4, while the inverter units mostly show SEER values between 4 and 5. The Indian manufacturer Godrej & Boyce, with the support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and HEAT GmbH, already started with the production and sale of their energy efficient and environmentally friendly hydrocarbon-based units (R-290, propane) in 2012. So far more than 100,000 units have been sold in India.
- **Thailand** is an important export country for single-split air conditioners: 1.8 m units are sold domestically per year while 7.5 m units are exported (both: 2014). Import figures are comparatively low with less than 0.5 m units. The penetration of air conditioning is high in the residential sector with more than 60%. Again, smaller cooling-only units with cooling capacities below 5 kW dominate the market. Inverter technology is not widespread. The major manufacturers are Mitsubishi Electric and Samsung with market shares of 30% and 20%; LG and Daikin together make up to 18%. Comparably, there are more units on the market with smaller capacities (< 6 kW), however, the entire range up to 12 kW is represented. The energy efficiency of a majority of units show EER values in the range of 3 to 4, only smaller units (2-3 kW cooling capacity) reach higher values up to EER values of 6. In the recent years, Thai producer Saijo Denki has been awarded several times for its energy-efficient products and is also active in expanding to overseas markets.
- **South Korean** sales amount to 1.4 m units per year; imports are around 0.4 m units and exports are in the magnitude of 2 m units (2014). The domestic market is almost exclusively dominated by single-split air conditioners. The current penetration rate is fairly high with around 70%. The share of inverter units on total sales is about 35% for lower capacity units, and about 95% for larger "packaged air conditioners". Reversible units only play a minor role with 7% of the total sales figures. A particular feature of the Korean market is the dominance of mid- and high capacity units (6-9 kW cooling capacity). In contrast to the other countries, the highest efficiency level is found for medium size products with cooling capacities around 7 kW. Samsung and LG dominate the South Korean domestic market with a combined market share of 80%.

Technology trends

The use of certain technologies can reduce the negative environmental impact of air conditioners. Strong positive effects can be achieved by using natural refrigerants and improving the energy efficiency.

The most dominant refrigerant used in room air conditioning in Asian countries is still HCFC-22 (ODP = 0.055, GWP = 1,810). Under the commitments of the Montreal Protocol, HCFCs have increasingly been replaced by HFCs, which do not have ozone depleting potential (ODP), but high global warming potential (GWP). At the moment a widely used alternative refrigerant to HCFC-22 is HFC-410A with a GWP of 2,088. Due to the current climate debate, the envisaged phase-down of HFCs in the European Union (Regulation (EU) No. 517/2014) and the recently agreed global phase-down of HFC (Kigali HFC amendment to the Montreal Protocol) there are increased considerations and efforts to replace high-GWP HFC by low-GWP refrigerants.

Currently various trends are observed: European countries focus on natural refrigerants (e.g. hydrocarbons) with a GWP ≤ 5 while some Asian countries focus on the refrigerant R-32 (GWP 675). Another recently introduced refrigerant group is represented by unsaturated HFCs (marketed as “HFOs” or “hydrofluoroolefins”). For an ecolabel, the high GWP refrigerant R-32 is unacceptable with regard to the current climate debate. Considering unsaturated HFCs, several studies have emphasised its negative environmental impacts, e.g. the formation of the persistent trifluoroacetic acid (TFA) but also the formation of hydrogen fluoride and carbonyl fluoride (created during combustion) which are both extremely toxic. Environmentally friendly and sustainable options are available with hydrocarbons (natural refrigerants), which are particularly suitable for room air conditioners. Furthermore, the use of hydrocarbons often improves the energy efficiency, and the air conditioners using them show a very good performance at high ambient temperatures. As hydrocarbons are flammable refrigerants, certain safety measures are required, e.g. limiting the initial charge depending on the room size/ventilation. Under China’s HCFC phase-out management plan (HPMP), some 15–20 production lines of Chinese manufacturers have already been converted to using R-290 (propane) as refrigerant.

The constant improvement of the energy efficiency of air conditioners is another trend that can be observed in many countries. This improvement is often driven by required minimum energy performance standards (MEPS). Technically, improvements in energy efficiency can be realised by introducing inverter technology, which allows variable speed drive of the compressor and thereby part-load operation. Inverter technology continuously regulates the compressor speed and thereby the energy consumption to match the required amount of cooling or heating. As air conditioners often operate in part-load mode, significant energy savings can be achieved (up to 25%), particularly in countries with temperate climates. While the conventionally used on/off units use the energy efficiency parameter Energy Efficiency Ratio (EER), the Seasonal Energy Efficiency Ratio (SEER) is used for systems with part load operation. Globally, the penetration rate of inverter technology in the AC market is around 30%, but much higher shares can be found, for example in the EU. Other features which improve the efficiency of air conditioners are electronic expansion valves (EEV), advanced heat exchanger design and variable speed fan motors. Similarly, filter cleaning technologies have a strong positive impact on reducing the energy consumption.

An improvement of the energy efficiency is often realised by increasing the heat exchanger, which translates into higher charge sizes. However, this is critical when using flammable refrigerants (such as R-290), and will conflict with the common safety standards at a certain point, e.g. DIN EN 60335-2-40. A detailed elaboration on this issue in this study finds that an efficiency level corresponding to A+++ in the European Union is incompatible with the current version of the product standard DIN EN 60335-2-40.

Ecological and economic impact analysis

Based on the methodological framework of the product sustainability analysis (PROSA), this study makes use of both, a comparative Life Cycle Assessment (LCA) of two product alternatives in order to analyse the ecological impacts as well as a comparative Life Cycle Cost (LCC) analysis aiming at a comparison of relative and absolute costs of two product alternatives.

Regarding the LCA, two air conditioners with different refrigerants are considered. Product A operates with R-410A. whereas Product B makes use of propane (R-290, C3H8, GWP = 3.3 kg CO_2e/kg), which is a mixture of difluoromethane (CH2F2, termed R-32) and pentafluoroethane (CHF2CF3, termed R-125) with an overall GWP of 2,088 kg CO_2e/kg. Both devices are single-split systems with a cooling capacity smaller than 5 kW. The life cycle of air conditioners is roughly divided into 4 stages: (1) production including raw material acquisition, (2) distribution, (3) use and (4) end-of-life treatment (i.e. cradle-to-grave). The energy efficiency of Product A is represented by the Seasonal Energy Efficiency Ratio (SEER) of 6.2 in the cooling mode and a Seasonal Coefficient of Performance (SCOP) of 4 in the heating mode. Product B is slightly more energy efficient with a SEER of 7 and an SCOP of 4.6. With regards to the leakage rate of the refrigerants a value of 5% is assumed. The overall life time of both devices is assumed to be 10 years.

In the base case scenario the air conditioners operate in a moderate climate zone (e.g. Germany). For both product alternatives this translates into times of use of 350 hours per year in the cooling mode and 1,400 hours per year in the heating mode.

Furthermore, in the base case scenario it is assumed that, in practice, 60% of the residual refrigerants are emitted directly to the atmosphere due to poor treatment in the end-of-life phase. Accordingly, only 40% of the refrigerants are assumed to be treated appropriately and lead to incineration. A comprehensive illustration of the assumptions of the LCA is provided in chapter 6.1.

The results of the base case scenario of the comparative LCA can be summarized as follows. For both alternative products, it is the use phase that accounts by far for the highest environmental impacts. With regards to GWP emissions during the total life cycle of product A, the use phase accounts for 85% (electricity consumption: 75% and leakage of refrigerants: 10%). The production phase of Product A accounts for 4% of the total GWP emissions over the product's life time. The distribution of the air conditioners and the production of refrigerants only have a marginal environmental impact for all the investigated impacts.

A similar picture results from the analysis of Product B. Accordingly, the use phase accounts for the largest proportion of GWP emissions with 93%, followed by the production phase with 6%. The GWP emissions from the use phase are almost fully due to electricity consumption, since the GWP of R290 is equal to 3.3 kg CO_2e/kg R-290 (as compared to 2088 kg CO_2e/kg R-410A). Also for Product B, the distribution of air conditioners and the production of refrigerants only have a marginal environmental impact of all investigated impacts.

In absolute terms, Product A (R-410A) causes GWP emissions of 1117.5 kg CO_2e over its lifetime of 10 years. As compared to Product A, the overall GWP emissions of Product B (R-290) amount to 778 kg, the latter saving around 30% of GWP emissions.

A first sensitivity analysis refers to the assumption of the leakage of the refrigerants in the end-of-life phase. While in the base case scenario 60% of the refrigerant load is assumed to leak in the end-of-life phase (and only 40% are taken to incineration appropriately), the first sensitivity analysis makes the assumption that 100% of the refrigerant are treated appropriately and taken to incineration. This results into GWP emission savings of 11% for Product A (R-410A) over the entire life cycle.

A second sensitivity analysis is carried out with regard to the climate zone in which the air conditioners operate. While in the base case scenario they operate in a moderate climate zone (such as Germany), sensitivity analysis 2 investigates changes of the results under the assumption that the products are operating in a tropical climate zone (such as Thailand).

Accordingly, the following assumptions change. With regards of the use times, no heating time is assumed whereas the cooling time is largely extended up to 2,920 hours per year. The lifespan of the devices are extended by 2 years up to 12 years. Also background datasets are changed according to the

Thai necessities (e.g. GHG emissions based on the electricity mix, etc.). Ceteris paribus, in the Thai scenario, the energy consumption in the use phase is around 25% higher as compared to the base case scenario in Germany.

Furthermore, the results of the Thai scenario show that product A (refrigerant R-410A) has a total annual GHG impact of 1963.16 kg CO_2e/a as compared to 1006.36 kg CO_2e/a for product B. Hence, the annual GHG savings of product B as compared to product A amount to around 49% (base case: 30%).

Complementary to the ecological impact assessment of the Life Cycle Assessment (LCA), an economic impact analysis is carried out using the instrument of total Life Cycle Costing (LCC). It includes all consumer expenditures throughout the lifetime of products, which is assumed to be 10 years in accordance to the LCA. It includes (1) purchasing prices, (2) installation costs, (3) repair and maintenance costs, (4) operating cost due to electricity consumption and (5) uninstallation costs. The underlying parameters for the calculation of the LCC are illustrated in chapter 6.2.

Firstly, the LCC analysis was carried out to estimate the relative cots shares of a typical single-split air conditioner operated in Germany. Accordingly, with 69% (3,869 €) by far the biggest share of the total LCCs are due to the operating costs resulting from electricity consumption, followed by 16% (900 €) related to the product's purchase, 9% (500 €) installation costs, another 4% (250 €) uninstalling costs and finally 2% (85 €) repair and maintenance costs. The total LCCs over 10 years of the modelled air conditioners are at 5,604 €.

Secondly, a comparative LCC was carried out to compare the LCCs of Product A (refrigerant: R-410A, see above) and Product B (refrigerant: R-290). The fact that Product B is assumed to be more energy efficient (see chapter 6.1) leads to total operating cost savings of around 500 € for product B as compared to product A (-9% of total LCCs of Product A). Hence, product B is not only favorable in terms of environmental impacts (see LCA results above) but also from an economic point of view.

Regulatory framework

Highly relevant regulations which concern single-split air conditioners in Europe are:

- Commission Regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for air conditioners and comfort fans (OJ L 72 of 10.3.2012, p. 7)
- Commission delegated regulation (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners (OJ L 178 of 6.7.2011, p. 1)
- Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated green-house gases and repealing Regulation (EC) No 842/2006 (OJ L 150 of 20.05.2014, p. 195)

Regulation (EU) No 517/2014 does not prohibit HFC, but these substances will become increasingly expensive due to the shortages (implemented HFC phase-down).

Furthermore, when flammable hydrocarbon refrigerants are used in room air conditioners, various standards have to be considered, notably: ISO 5149, DIN EN 378, DIN EN 60335-2-40.

Award criteria

The award criteria of the ecolabel "The Blue Angel" include the following criteria for which specific requirements have been formulated:

- Type of refrigerant
- Energy efficiency in the cooling and heating mode, including the use of cleaning technology for filters
- Noise emissions
- Material requirements (exclusion of hazardous substances)
- Environmentally friendly product design
- Sales / Distribution
- Services
- Product documentation
- Operating instructions
- Installation and service manual

Only the most important criteria – type of refrigerant and energy efficiency – are highlighted in this summary.

Regarding the current safety standards, the ecolabel "The Blue Angel claims an energy efficiency of SEER ≥7 in the cooling mode and for the heating mode the Seasonal Coefficient of Performance (SCOP) ≥4.6. Furthermore the air conditioners must be free from halogenated refrigerants; the use of the natural refrigerant ammonia is not allowed, due to its toxicity.

Comparison of selected Asian ecolabels

All partner countries except India do have ecolabels for air conditioners, addressing various aspects, such as its refrigerant, energy efficiency, sound impact, hazardous substances in components, recycling, etc.

For the refrigerant, these ecolabels claim an ODP of zero. However, the GWP threshold is set to 2,500 (Thailand, South Korea) or is not defined at all (China). Regarding the efficiency, the ecolabels from Thailand and South Korea refer to the highest national energy efficiency labelling class, the Chinese ecolabel generally refers to the corresponding national energy efficiency standards.

Zusammenfassung

Das Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB) hat, zusammen mit dem Umweltbundesamt (UBA) das Forschungsprojekt „Entwicklung eines Umweltzeichens ‚Blauer Engel' für Klimageräte – ein nationales Zeichen mit internationaler Wirkung" in Auftrag gegeben. Es konzentriert sich auf die Produktgruppe der sogenannten Single-Split-Klimageräte.

Dieser wissenschaftlich-technische Hintergrundbericht ermöglicht die Ableitung von Vergabekriterien für das Umweltzeichen „Der Blaue Engel" in Bezug auf Single-Split-Klimageräte.

Hintergrund

Klimageräte werden weltweit zunehmend dazu eingesetzt, angenehme Temperaturen in Wohnhäusern und gewerblichen Gebäuden zu erzeugen, darüber hinaus aber auch, um eine gute Leistungsfähigkeit in Bürogebäuden zu gewährleisten. Der Weltmarkt an verkauften Raumklimageräten umfasst etwa 105 Mio. (Millionen) verkaufter Geräte (2014). In vielen Ländern werden jedoch jährliche Wachstumsraten von 10-15% erzielt. Der weitverbreitete Einsatz von Klimageräte ist mit negativen Auswirkungen auf die Umwelt verbunden: (1) Emissionen durch den Austritt von Kältemitteln (direkte Emissionen) und (2) Emissionen infolge des Energieverbrauchs (indirekte Emissionen) tragen zur globalen Erwärmung bei – und dies, obwohl bereits umweltfreundliche Alternativen zur Verfügung stehen.

Verschiedene internationale Vereinbarungen und regionale sowie nationale Instrumente wurden bereits eingeführt, um diese negativen Auswirkungen auf die Umwelt zu verringern. Das Protokoll von Montreal hat die Verwendung ozonschichtabbauender Kältemittel wie FCKWs und HFCKWs seit 1989 wirksam eingedämmt. Klimarelevante HFKWs, die weithin als Alternativen zu Stoffen eingeführt wurden, die zu einem Abbau der Ozonschicht führen, wurden im Protokoll von Kyoto zum Rahmenübereinkommen der Vereinten Nationen über Klimaänderungen (UNFCCC) aufgeführt. HFKWs wurden zudem vor kurzem durch das historische Abkommen von Kigali in das Montrealer Protokoll aufgenommen. Ziel der Erweiterung des Protokolls ist, die Verwendung von HFKWs schrittweise zu beschränken. Darüber hinaus haben die Europäische Union und verschiedenen Länder bereits Gesetze zur Beschränkung der Verwendung von HFKWs formuliert, sowie Energiekennzeichnungsprogramme und Mindestanforderungen an die Energieeffizienz (MEPS) eingeführt, mit dem Ziel, den Energieverbrauch von Klimageräten zu verringern.

Der Blaue Engel bietet hier ein weiteres Steuerungsinstrument, um eine Markttransformation zugunsten umweltfreundlicher Produkte und einer erhöhten Nachhaltigkeit zu unterstützen. Viele asiatische Länder haben bereits Umweltzeichen für Klimageräte eingeführt.

Diese Studie analysiert die wichtigsten Märkte, Technologietrends und den derzeitigen Rechtsrahmen im Bereich Klimageräte. Außerdem wird eine Ökobilanz (LCA) durchgeführt, welche die Umweltverträglichkeit der Verwendung von umweltfreundlichen Klimageräten analysiert, sowie eine Lebenszykluskostenanalyse (LCA), welche wirtschaftlichen Auswirkungen beleuchtet. Schließlich werden die in Asien vorhandenen Umweltzeichen miteinander verglichen. Damit folgt diese Studie dem methodischen Aufbau des vom Öko-Institut e.V. entwickelten Ansatzes „Product Sustainability Assessment (PROSA)" (Grießhammer et al. 2007), der im Folgenden erlaubt, Vergabekriterien für den Blauen Engel abzuleiten.

Allgemein formuliert, ist PROSA eine Methode zur strategischen Analyse und Bewertung von Produkt-Portfolios, Produkte und Dienstleistungen. Sie umfasst somit komplette Produktlebenszyklen und Wertschöpfungsketten; sie analysiert und bewertet die ökologischen, wirtschaftlichen und (sofern möglich) sozialen Chancen und Risiken zukünftiger Entwicklungspfade. PROSA ist eine prozessorientierte und iterative Methode, die Budget- und Zeitrestriktionen berücksichtigt. Sie bedient sich dabei soweit als möglich bestehender und etablierter Einzelwerkzeuge (Megatrendanalyse, Ökobilanz/Lebenszyklusbewertung, Lebenszykluskostenbewertung etc.). PROSA wurde in der Vergangenheit bereits mehrfach angewendet, um Umweltkriterien für zahlreiche Produktgruppen für den Blauen Engel abzuleiten (Gröger et al. 2013). Weitere Informationen zum methodischen Rahmen sind Kapitel 2 zu entnehmen.

Die Vielzahl unterschiedlicher Raumklimageräte kann je nach Anordnung des Innengeräts (Verdampfer), des Außengeräts (Verflüssiger) sowie der Anzahl der Innengeräte grob in drei Gruppen eingeteilt werden: 1) Monoblock-Klimageräte, 2) Single-Split-Klimageräte und (3) Multisplit-Klimageräte und VRF-Klimasysteme mit regelbarem Kältemittelmassenstrom (VRF).

Im Rahmen dieses Projektes ist vor allem die Produktgruppe der Single-Split-Klimageräte von Interesse. Hier befindet sich der Verdampfer im Inneren des Gebäudes, das gekühlt oder beheizt werden soll, während sich der Verflüssiger außerhalb des Gebäudes befindet. Beide Teile werden über eine Rohrleitung miteinander verbunden. Solche Systeme werden sowohl im Wohnbereich als auch im Gewerbesektor eingesetzt. Die primäre Funktion von Single-Split-Klimageräten sind Kühlen, Heizen oder beides. Geräte, die in der Lage sind, sowohl zu kühlen als auch zu heizen, sind sogenannte reversible Systeme. Im Gegensatz zu reinen Kühlgeräten werden reine Heizgeräte (Wärmepumpen) hier nicht für das Umweltzeichen betrachtet. Mögliche sekundäre Funktionen sind Umwälzung, Entfeuchtung und Reinigung der Luft. Hinsichtlich einer detaillierten Definition der betrachteten Produktgruppe verweist dieser Bericht auf Verordnung (EU) Nr. 626/2011 (Art. 2), ohne jedoch Zweikanal- und Einkanalklimageräte einzubeziehen.

Der Markt für Klimageräte

Das Marktvolumen für private und gewerbliche Klimageräte beträgt rund 105 Mio. verkaufte Einheiten pro Jahr mit einem Marktwert von mehr als 95 Mrd. US-Dollar (2014). Die Hauptmärkte befinden sich in Asien/Südostasien. China ist der wichtigste Absatzmarkt weltweit, gefolgt von den USA. Split-Systeme (kanalfreie Systeme und Kanalsysteme) machen den größten Marktanteil an Klimageräten weltweit aus (> 85 Mio. verkaufte Geräte pro Jahr im Jahr 2014). Insbesondere kanalfreie Single-Split-Geräte – die Gruppe, auf der beim Blauen Engel der Schwerpunkt liegt – dominiert eindeutig den Weltmarkt, vor allem in den asiatischen und südostasiatischen Ländern. Weltweit haben Single-Split-Geräte deutlich höhere Marktanteile als Monoblock-Geräte. In einigen Ländern kann die Situation davon jedoch abweichen. In Deutschland zum Beispiel ist der Anteil der Gerätetypen gleich hoch.

Weltweit haben die **asiatischen/südostasiatischen** Volkswirtschaften nicht nur die meisten Abnehmer, sondern auch die größten Produktionskapazitäten für Klimageräte (z. B. China, Thailand, Indien). Insbesondere China und Thailand sind hier wichtige Exporteure, wobei die Anforderungen der verschiedenen Zielmärkte bei der Ausfuhr der Geräte erfüllt werden muss. Dies bedeutet, dass lokal mehrere Produktionslinien vorhanden sein können, von denen jede für die Produktion bestimmter Märkte, einschließlich der des heimischen Marktes, vorgesehen ist. In Asien/Südostasien werden etwa 65 Mio. Klimageräte pro Jahr nachgefragt (2014), wobei die größte Nachfrage in China besteht. Abgesehen von Indien und den Philippinen sind Single-Split-Klimageräte am Markt vorherrschend. Viele dieser tropischen Länder benutzen Klimageräte, die nur über die Kühlfunktion verfügen.

Der Markt für Raumklimageräte in **Europa** beträgt rund 6 Mio. verkaufte Einheiten pro Jahr (2014). Marktdominierend sind hier Russland (26%) sowie die Türkei und Italien (jeweils 14%). Die anderen in Europa vorhandenen Märkte sind vergleichsweise klein (< 10%). Die beliebtesten Produkte sind Split-Klimageräte. Der deutsche Raumklimagerätemarkt ist mit rund 190.000 verkaufter Einheiten im Jahr relativ klein. So gut wie alle Geräte werden importiert. Rund 70.000-80.000 der nachgefragten Geräte sind Single-Split-Klimageräte (meist reversible Geräte). Kompaktklimageräte (bewegliche Geräte) weisen ähnliche Absatzmengen auf und sind somit ebenso bedeutsam. Zentrale Klimageräte sind in Deutschland weit verbreitet, z. B. Flüssigkeitskühler oder VRF-Systeme. Die Marktdurchdringung von Raumklimageräten in privaten Haushalten ist vergleichsweise gering (< 5%), allerdings wird ein starker Anstieg der Verkaufszahlen prognostiziert; bis 2040 werden Bestandszahlen von rund 2,8 Mio. Geräten erwartet. Die Systeme verwenden ausschließlich HFKWs und weisen zum Teil eine hohe Energieeffizienz auf (mit Werten des jahreszeitenbedingten Energiewirkungsgrads SEER (seasonal energy efficiency ratio) von bis zu 10).

Mit einem Anteil von 80-90% an der Gesamtproduktion von Klimageräten ist **China** mit Abstand der weltweit größte Akteur in diesem Bereich. Der Markt an Single-Splits beträgt rund 45 Mio. verkaufte Geräte pro Jahr (2014), weitere 19 Mio. Einheiten werden exportiert. Das chinesische Einfuhrvolumen hingegen ist unerheblich. Innerhalb des Landes besteht die größte Nachfrage nach Klimageräten in den östlichen urban geprägten Gebieten („Magacities"). Im Durchschnitt sind etwa 50% der privaten chinesischen Haushalte mit einem Klimagerät (20-25% in ländlichen Gebieten) ausgestattet. Damit ist China unter den Ländern Asiens eines, das mit die höchste Marktdurchdringung bei Klimageräten aufweist. Der bevorzugte Typ ist das Splitsystem (Single- und Multi-Splits) mit Kühlleistungen von maximal 5 kW. Die Mehrzahl der verkauften Raumklimageräte hat eine Wärmefunktion, verfügt also über eine Wärmepumpe, da diese Geräte nicht viel teurer sind als solche, die nur die Kühlfunktion haben. Raumklimageräte mit energieeffizienter Inverter-Technik machen derzeit rund 50% der jährlichen Verkaufszahlen aus, und dieser Anteil wird voraussichtlich weiter steigen. Führende Hersteller mit einem Gesamtmarktanteil von ca. 60% sind Gree, Midea und Haier. Der Wirkungsgrad ihrer Geräte im Kühlbetrieb erreicht einen SEER-Wert von 5. Darüber hinaus planen Gree, Midea und Haier mit Unterstützung des Multilateralen Fonds (MLF) des Montrealer Protokolls die Einführung Kohlenwasserstoff-basierter Single-Split-Klimageräte.

Der **indische** Markt an Klimageräten hat in der Vergangenheit nicht das erwartete Potenzial erreicht, obwohl sich die Verkaufszahlen in den letzten 10 Jahren fast verdreifacht haben. Derzeit werden rund 3 Mio. Single-Splits pro Jahr auf dem heimischen Markt abgesetzt (2014). Etwa 0,5 Mio. Geräte werden importiert und exportiert. Single-Split-Klimageräte haben in vergangenen Jahren stetig Marktanteile hinzugewonnen und übersteigen nun den Anteil an Fensterklimageräten. Im Allgemeinen sind Klimageräte in Indien relativ preiswert im Vergleich zu anderen Ländern; indische Verbraucher scheuen in der Regel höhere Investitionskosten. Die Marktdurchdringungsrate in privaten Haushalten ist mit weniger als 5% relativ niedrig, wobei Klimageräte, die nur über einer Kühlfunktion verfügen, den Markt beherrschen. Allerdings sind bei reversiblen Systemen hohe Zuwachsraten im Norden Indiens zu beobachten. Wurden im Jahr 2008 noch vor allem Einheiten mit größeren Kühlleistungen (> 5 kW) verkauft, so hat sich diese Situation inzwischen verändert. Inverter-Klimageräte sind zwar noch immer von untergeordneter Bedeutung, zeigen jedoch mit 25% deutliche Wachstumsraten. Der Wirkungsgrad indischer Kühlgeräte bewegt sich zwischen EER-Werten von 3 bis 4, während Invertergeräte meist SEER-Werte zwischen 4 bis 5 aufweisen. Der indische Hersteller Godrej & Boyce hat mit Unterstützung der deutschen Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH und der HEAT GmbH bereits im Jahr 2012 mit der Produktion und dem Verkauf ihrer energieeffizienten und umweltfreundlichen Kohlenwasserstoff-basierten Geräte (R-290, Propan) begonnen. Bisher wurden mehr als 100.000 Geräte in Indien verkauft.

Thailand ist ein wichtiges Exportland für Single-Split-Klimageräte: im Inland werden 1,8 Mio. Geräte pro Jahr verkauft, während 7,5 Mio. Geräte jährlich exportiert werden. Mit weniger als 0,5 Mio. Geräten sind die Importzahlen vergleichsweise niedrig. Die Marktdurchdringung von Klimageräten in Privatwohnungen ist mit mehr als 60% relativ hoch. Auch hier dominieren kleinere Geräte, die nur über eine Kühlfunktion verfügen und Kühlleistungen unter 5 kW haben, den Markt. Die Inverter-Technik ist hingegen nicht weit verbreitet. Mit Marktanteilen von 30 bzw. 20% sind Mitsubishi Electric und Samsung die größten Hersteller; LG und Daikin haben zusammen 18% Marktanteil. Es gibt zwar mehr Geräte mit relativ niedriger Leistung (< 6 kW) auf dem Markt, doch ist die gesamte Spannbreite von bis zu 12 kW ebenso vertreten. Bei den meisten Geräten liegt die Energieeffizienz bei EER-Werten von 3 bis 4, nur kleinere Geräte (ca. 2-3 kW Kühlleistung) erreichen höhere EER-Werte von bis zu 6. Der thailändische Hersteller Saijo Denki wurde in den letzten Jahren mehrmals für seine energieeffizienten Produkte ausgezeichnet. Darüber hinaus exportiert er verstärkt in Übersee-Märkte.

Die Umsätze **Südkoreas** belaufen sich auf 1,4 Mio. Geräte pro Jahr; das Importvolumen beträgt rund 0,4 Mio. Geräte und Exporte bewegen sich in der Größenordnung von 2 Mio. Geräten. Der Inlandsmarkt wird fast ausschließlich von Single-Split-Klimageräten beherrscht. Die Marktdurchdringung ist mit rund 70% relativ hoch. Der Anteil der Inverter-Geräte am Gesamtumsatz macht ca. 35% bei Geräten mit geringerer Leistung aus, während sie bei größeren Monoblockgeräten ca. 95% beträgt. Reversible Einheiten spielen mit 7% der Gesamtverkaufszahlen eine untergeordnete Rolle. Eine Besonderheit des koreanischen Marktes ist die Dominanz von Geräten im mittleren und hohen Leistungsbereich (6-9 kW Kühlleistung). Im Gegensatz zu anderen Ländern ist in Korea der höchste Wirkungsgrad bei mittelgroßen Geräten mit Kühlleistungen von ca. 7 kW anzutreffen. Mit einem gemeinsamen Marktanteil von 80% dominieren Samsung und LG den südkoreanischen Inlandsmarkt.

Technologietrends

Der Einsatz bestimmter Techniken kann die negativen Umweltauswirkungen von Klimageräten reduzieren. Ausgesprochen positiv können sich die Verwendung natürlicher Kältemittel und eine Verbesserung der Energieeffizienz auswirken.

Das am häufigsten für Raumklimageräte in asiatischen Ländern eingesetzte Kältemittel ist noch immer R-22 (ODP = 0,055, GWP = 1. 810). Gemäß den Verpflichtungen des Montrealer Protokolls wurden HFCKWs zunehmend durch HFKWs ersetzt, die zwar kein Ozonabbaupotential (ODP) besitzen, jedoch ein hohes Treibhauspotenzial (GWP). Zurzeit ist R-410A mit einem GWP-Wert von 2.088 ein weit verbreitetes Ersatz-Kältemittel. Aufgrund der aktuellen Klimadebatte sowie vor dem Hintergrund der geplanten schrittweisen Beschränkung von HFCKWs in der Europäischen Union (Verordnung (EU) Nr. 517/2014) und des kürzlich beschlossenen weltweiten schrittweisen Ausstiegs aus der Produktion und Verwendung von HFKWs (Kigali-Abkommen zu HFKWs — Änderung des Montrealer Protokolls) gibt es verstärkt Überlegungen und Anstrengungen, HFKWs mit hohem GWP durch Kältemittel mit einem niedrigen GWP-Wert zu ersetzen.

Derzeit sind verschiedene Trends zu beobachten: Die europäischen Länder konzentrieren sich auf natürliche Kältemittel (z.B. Kohlenwasserstoffe) mit einem GWP ≤ 5, während einige asiatische Länder auf das Kältemittel R-32 (GWP=675) setzen. Eine weitere kürzlich eingeführte Kältemittelgruppe sind ungesättigte HFKWs (vermarktet als "HFOs" oder "Hydrofluorolefine"). Für ein Umweltzeichen ist der hohe GWP-Wert des Kältemittels R-32 vor dem Hintergrund der aktuellen Klimadebatte inakzeptabel. Im Hinblick auf ungesättigte HFKWs haben mehrere Studien die negativen Umweltauswirkungen dieser Gruppe unterstrichen, z.B. die Bildung der persistenten Trifluoressigsäure (TFA), sowie die Bildung der beiden extrem toxischen Stoffe Fluorwasserstoff und Carbonylfluorid (die bei der Verbrennung entstehen). Umweltfreundliche und nachhaltige Alternativen stehen mit Kohlenwasserstoffen (natürliche Kältemittel), die sich besonders für Raumklimageräte eignen, zur Verfügung. Darüber hinaus verbessert die Verwendung von Kohlenwasserstoffen oft die Energieeffizienz. Außerdem bieten Klimageräte, die diese Stoffe einsetzen, hervorragende Leistungen bei hohen Umgebungstemperaturen. Da Kohlenwasserstoffe brennbare Kältemitteln sind, sind bestimmte Sicherheitsmaßnahmen erforderlich, z. B. eine Begrenzung der Füllmenge je nach Raumgröße/Belüftung. Gemäß des chinesischen Managementplans zum Ausstieg aus der Herstellung und Verwendung von HFCKWs (HCFC phase out management plan, HPMP) sind etwa 15 – 20 Produktionslinien chinesischer Hersteller bereits auf R-290 (Propan) als Kältemittel umgestellt worden.

Die kontinuierliche Steigerung der Energieeffizienz ist ein weiterer Trend, der in vielen Ländern beobachtet werden kann. Diese Verbesserung ist häufig auch das Ergebnis von Mindeststandards an die Energieeffizienz (MEPS). Eine Verbesserung der Energieeffizienz ist technisch durch die Einführung der Inverter-Technik realisierbar, wodurch ein drehzahlvariabler Antrieb des Kompressors und damit

Teillastbetrieb ermöglicht wird. Die Inverter-Technik regelt kontinuierlich die Drehzahl des Kompressors und damit den Energieverbrauch entsprechend dem jeweiligen Kühl- oder Heizbedarf. Da Klimageräte oft im Teillastmodus betrieben werden, können insbesondere in Ländern der gemäßigten Klimazonen erhebliche Energieeinsparungen (bis zu 25%) erzielt werden. Während die herkömmlich verwendeten ein-/ausschalten Geräte als Energieeffizienzparameter den Energiewirkungsgrad (EER) benutzen, wird der jahreszeitbedingte Energiewirkungsgrad (SEER) für Systeme mit Teillastbetrieb verwendet. Weltweit liegt die Marktdurchdring der Inverter-Technik auf dem Markt für Raumklimageräte bei etwa 30%. Es sind jedoch, u.a. in der EU, auch deutlich höhere Anteile zu verzeichnen. Weitere Komponenten, die die Effizienz von Klimageräten verbessern, sind elektronische Expansionsventile (EEV) und moderne Wärmeübertrager sowie drehzahlgeregelte Lüftermotoren. In ähnlicher Weise wirken sich Filterreinigungstechniken ausgesprochen positiv im Hinblick auf eine Verringerung des Energieverbrauchs aus.

Eine Steigerung der Energieeffizienz wird oft durch eine Vergrößerung des Wärmeübertragers erzielt, was größere Füllmengen zur Folge hat. Dies ist jedoch bei der Verwendung von brennbaren Kältemitteln (z. B. R-290) kritisch, und steht punktuell im Widerspruch zu den allgemeinen Sicherheitsstandards, z. B. der DIN EN 60335-2-40. Eine eingehende Untersuchung dieses Problems im Rahmen der vorliegenden Studie kommt zu dem Ergebnis, dass ein Wirkungsgrad, welcher der Energieeffizienzklasse A+++ entspricht, in der Europäischen Union nicht mit der aktuellen Version des Produktstandards DIN EN 60335-2-40 vereinbar ist.

Analyse der ökonomischen und ökologischen Auswirkungen

Auf der Grundlage des methodischen Rahmens der Produkt-Nachhaltigkeitsbewertung (PROSA) nutzt diese Studie einerseits die vergleichende Ökobilanz (Lebenszyklusbewertung/LCA) zur Analyse der ökologischen Auswirkungen von zwei Produktalternativen sowie eine vergleichende Lebenszykluskostenanalyse (LCC) mit dem Ziel, die relativen und absoluten Kosten von zwei Produktalternativen miteinander zu vergleichen.

Anhand der Ökobilanz (LCA) werden zwei Klimageräte mit unterschiedlichen Kältemitteln betrachtet. Während in Produkt A mit R-410A zum Einsatz kommt, einer Mischung aus Difluormethan (CH_2F_2, bezeichnet als R-32) und Pentafluorethan (CHF_2CF_3, bezeichnet als R-125) mit einem Gesamt-Klimapotenzial von 2.088 kg CO_2e/kg), arbeitet Produkt B mit Propan (R-290, C_3H_8, GWP = 3,3 kg CO_2e/kg. Beide Geräte sind Single-Split-Geräte mit einer Kühlleistung, die kleiner ist als 5 kW. Der Lebenszyklus von Klimageräten kann grob in 4 Stufen untergliedert werden: (1) Produktion einschließlich Rohmaterialbeschaffung, (2) Vertrieb, (3) Nutzung und (4) Entsorgung (d.h. „von der Wiege bis zur Bahre“). Die Energieeffizienz von Produkt A wird durch einen jahreszeitbedingten Energiewirkungsgrad (SEER) von 6,2 im Kühlbetrieb und eine jahreszeitbedingte Leistungszahl (SCOP) von 4 im Heizbetrieb abgebildet. Produkt B ist mit einem SEER von 7 und einem SCOP von 4,6 etwas sparsamer hinsichtlich des Energieverbrauchs. Es wird eine Leckagerate der Kältemittel von 5% angenommen. Hinsichtlich der Gesamtlebensdauer beider Geräte geht man von 10 Jahren aus.

Im Basisszenario werden die Klimageräte in einer gemäßigten Klimazone (z.B. Deutschland) betrieben. Unter dieser Maßgabe werden bei beiden Produktalternativen jährliche Nutzungszeiten von 350 Stunden im Kühlbetrieb und 1.400 Stunden im Heizbetrieb angenommen.

Darüber hinaus wird im Basisszenario davon ausgegangen, dass in der Praxis 60% der Kältemittelrückstände aufgrund schlechter Entsorgungspraktiken direkt in die Atmosphäre abgegeben werden. Folglich ist davon auszugehen, dass nur 40% der Kältemittel angemessen entsorgt und einer Verbrennung zugeführt werden. Eine ausführliche Darstellung der im Rahmen der Ökobilanz getroffenen Annahmen ist in Kapitel 6.1 enthalten.

Die Ergebnisse des Basisszenarios der vergleichende Ökobilanz können wie folgt zusammengefasst werden: Bei beiden Produkten ist es die Nutzungsphase, die mit Abstand für die größten Umweltbelastungen verantwortlich ist. In Bezug auf die während des gesamten Lebenszyklus des Produktes A erzeugten Treibhausgasemissionen entfallen 85% auf die Nutzungsphase (Stromverbrauch: 75%, Kältemittelemissionen: 10%). Auf die Produktionsphase von Produkt A entfallen über die Gesamtlebensdauer des Produktes 4% des Gesamtausstoßes klimawirksamer Gase. Der Vertrieb der Klimageräte und die Kältemittelproduktion haben bei allen untersuchten Wirkungskategorien nur geringfügige Auswirkungen, was die Klimabelastung angeht.

Ein ähnliches Bild ergibt sich bei der Untersuchung von Produkt B. Mit 93% entfällt der größte Teil der GWP-Emissionen auf die Nutzungsphase, gefolgt von der Produktionsphase mit 6%. Die der Nutzungsphase zuzuschreibenden Treibhausgasemissionen sind fast vollständig auf den Stromverbrauch zurückzuführen, da der GWP-Wert von R-290 3,3 kg CO_2e/kg R-290 (im Vergleich zu 2.088 kg CO_2e/kg für R-410A) entspricht. Auch bei Produkt B wirken sich der Vertrieb des Klimageräts und die Kältemittelproduktion nur marginal in Bezug auf alle untersuchten Umweltwirkungen aus.

In absoluten Zahlen ausgedrückt verursacht Produkt A (R-410A) Treibhausgasemissionen von 1.117,5 kg CO_2e über seine gesamte Lebensdauer von 10 Jahren. Im Vergleich dazu betragen die Gesamtemissionen von Produkt B (R290) 778,9 kg CO_2e. Damit werden bei diesem Produkt rund 30% weniger Treibhausgase ausgestoßen.

Eine erste Sensitivitätsanalyse beruht auf unterschiedlichen Annahmen hinsichtlich des Kältemittelaustritts bei der Entsorgung (End-of-life-Phase). Während im Basisszenario angenommen wird, dass 60% des Kältemittels in der End-of-Life-Phase austreten (und nur 40% ordnungsgemäß der Verbrennung zugeführt werden), wird in der ersten Sensitivitätsanalyse davon ausgegangen, dass 100% des Kältemittels ordnungsgemäß entsorgt und verbrannt werden. Diese Annahme führt zu 11% geringeren Treibhausgasemissionen bei Produkt A (R-410A) über den gesamten Lebenszyklus.

Im Hinblick auf die Klimazone, in denen die Klimageräte eingesetzt werden, wurde eine zweite Sensitivitätsanalyse durchgeführt. Während die Geräte im Basisszenario in einer gemäßigten Klimazone (z. B. Deutschland) betrieben werden, untersucht die zweite Sensitivitätsanalyse, wie sich die Ergebnisse unter der Annahme verändern, dass die Geräte in einer tropischen Klimazone (z. B. in Thailand) genutzt werden.

Dementsprechend verändern sich die Annahmen. Hinsichtlich der Nutzungszeiten geht man davon aus, dass kein Heizbetrieb stattfindet, während die Kühlzeit mit bis zu 2.920 Stunden pro Jahr deutlich höher ausfällt als im Basisszenario. Die Lebensdauer der Geräte verlängert sich um 2 Jahre und beträgt damit bis zu 12 Jahren. Darüber hinaus werden Hintergrund-Datensätze entsprechend der Gegebenheiten in Thailand (z.B. THG-Emissionen auf der Grundlage eines Strommixes, etc.) geändert. Ceteris paribus fällt der Energieverbrauch in der Nutzungsphase im thailändischen Szenario um rund 25% höher aus als im Basisszenario in Deutschland.

Die Ergebnisse des thailändischen Szenarios zeigen ferner, dass Produkt A (Kältemittel R-410A) mit THG-Gesamtemissionen von jährlich 1.963,16 kg CO_2e/a im Vergleich zu 1.006,36 kg CO_2e/a für Produkt B zu Buche schlägt. Im Vergleich zu Produkt A belaufen sich die Einsparungen an THG-Emissionen bei Produkt B pro Jahr auf rund 49% (Basisszenario: 30%).

Ergänzend zu der ökologischen Folgenabschätzung des Ökobilanz (Lebenszyklusbewertung/LCA), wurde eine Analyse der wirtschaftlichen Auswirkungen mit dem Instrument der Lebenszykluskostenrechnung (total Life Cycle Costing/LCC) durchgeführt. Sie enthält alle Verbraucherausgaben, die im Laufe der gesamten Lebensdauer der Geräte – die in Übereinstimmung mit der Ökobilanz auf 10 angesetzt ist – gemacht wurden. Dies sind (1) Einkaufspreise, (2) Installationskosten, (3) Reparatur- und Wartungskosten, (4) Betriebskosten infolge des Stromverbrauchs und (5) Kosten der Deinstallation.

Die zugrundeliegenden Parameter für die Berechnung der Lebenszykluskosten werden in Kapitel 6.2 näher erläutert.

Zunächst wurde die LCC-Analyse durchgeführt, um die relativen Kostenanteile eines typischen Single-Split-Klimageräts in Deutschland einschätzen zu können. Den mit Abstand größten Anteil an den Lebenszyklusgesamtkosten stellen demnach mit 69% (3.869 €) die Betriebskosten dar, die auf den Stromverbrauch zurückzuführen sind, gefolgt von 16% (900 €) für den Kauf des Produkts, 9% (500 €) für die Installationskosten, weitere 4% (250 €) für die Kosten der Deinstallation und schließlich 2% (85 €) Reparatur- und Wartungskosten. Die Gesamtkosten der modellierten Klimageräte über den gesamten Lebensweg von 10 Jahren liegen somit bei 5.604 €.

Im Anschluss wurde eine vergleichende LCC-Analyse durchgeführt, um die Lebenszykluskosten des Produkts A (Kältemittel: R-410A, siehe oben) mit denen des Produkts B (Kältemittel: R-290) zu vergleichen. Die Tatsache, dass Produkt B den Annahmen zufolge das energieeffizientere Gerät ist (siehe Kapitel 6.1) führt zu Einsparungen an Betriebskosten in Höhe von rund 500 € für Produkt B im Vergleich zu Produkt A (-9% der gesamten Lebenszykluskosten des Produktes A). Produkt B ist also nicht nur vorteilhafter in Bezug auf die Umweltauswirkungen (siehe Ökobilanzergebnisse oben), sondern auch aus ökonomischer Sicht günstiger.

Rechtliche Rahmenbedingungen

Folgende wichtige einschlägige Bestimmungen in Bezug auf Single-Split-Klimageräte existieren in der EU:

- Verordnung (EU) Nr. 206/2012 der Kommission vom 6. März zur Durchführung der Richtlinie 2009/125/EG des Europäischen Parlaments und des Rates im Hinblick auf die Festlegung von Anforderungen an die umweltgerechte Gestaltung von Raumklimageräten und Komfortventilatoren (ABl. L 72 vom 10.3.2012, S. 7)
- Delegierte Verordnung (EU) Nr. 626/2011 der Kommission vom 4. Mai 2011 zur Ergänzung der Richtlinie 2010/30/EU des Europäischen Parlaments und des Rates im Hinblick auf die Kennzeichnung von Luftkonditionierern in Bezug auf den Energieverbrauch (ABl. L 178 vom 6.7.2011, S. 1)
- Verordnung (EU) Nr. 517/2014 des Europäischen Parlaments und des Rates vom 16. April 2014 über fluorierte Treibhausgase und zur Aufhebung der Verordnung (EG) Nr. 842/2006 (ABl. L 150 vom 20.05.2014, S. 195)

Richtlinie (EU) Nr. 517/2014 verbietet HFKW zwar nicht, doch werden diese Stoffe infolge der darin festgelegten Verknappung (phase down-Szenario) immer teurer werden.

Für den Einsatz brennbarer Kältemittel auf der Basis von Kohlenwasserstoffen in Raumklimageräten sind darüber hinaus verschiedene Normen zu berücksichtigen, insbesondere: ISO 5149, DIN EN 378, DIN EN 60335-2-40.

Die Vergabekriterien

Die Vergabekriterien des Umweltzeichens „Der Blaue Engel" beinhalten die folgenden Kriterien, für die spezifische Anforderungen formuliert wurden:

- Kältemitteltyp
- Energieeffizienz im Heiz- und Kühlbetrieb, einschließlich Einsatz einer Reinigungstechnik für Filter
- Lärmemissionen
- Materialanforderungen (Verzicht auf gefährliche Stoffe)
- umweltfreundliche Produktgestaltung

- Verkauf / Vertrieb
- Dienstleistungen
- Produktdokumentation
- Bedienungsanleitung
- Installation und Service-Handbuch

In dieser Übersicht werden nur die wichtigsten Kriterien – Kältemitteltyp und Energieeffizienz – hervorgehoben.

Bezüglich der geltenden Sicherheitsnormen fordert der Blaue Engel für den Kühlmodus einen Energiewirkungsgrad (SEER) von ≥7 und für den Heizbetrieb eine jahreszeitbedingte Leistungszahl (SCOP) ≥4.6. Außerdem müssen die Geräte frei von halogenierten Kältemitteln sein; der Einsatz des natürlichen Kältemittels Ammoniak ist aufgrund seiner Toxizität nicht zulässig.

Vergleich von ausgewählten asiatischen Umweltzeichen

Alle Partnerländer mit Ausnahme von Indien haben Umweltzeichen für Klimageräte, die verschiedene Aspekte wie z. B. Kältemittel, Energieeffizienz, Schallbelastung, gefährliche Stoffe in Bauteilen, Recycling etc. berücksichtigen.

In Bezug auf das Kältemittel fordern diese Umweltzeichen ein ODP von Null. Der GWP-Grenzwert wurde jedoch auf 2.500 festgelegt (Thailand, Südkorea) bzw. überhaupt nicht definiert (China). Hinsichtlich der Effizienz beziehen sich die Umweltzeichen aus Thailand und Südkorea für die Kennzeichnung auf die höchste Energieeffizienzklasse, während sich chinesische Umweltzeichen in der Regel auf die entsprechenden nationalen Vorgaben zur Energieeffizienz beziehen.

List of Figures

List of Tables

Abbreviations

AC	Air conditioner / air conditioning
APF	Annual performance factor
BEE	Bureau of Energy Efficiency (India)
CFC	Chlorofluorocarbons
BSRIA	Building Services Research and Information Association
COP	Coefficient of performance
CSPF	Cooling seasonal performance factor
EER	Energy efficiency ratio
EoL	End of life
ErP	Energy related product
EU	European Commission
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit [German Society for International Cooperation]
GWP	Global warming potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HF	Hydrofluoric acid
HFC	Hydrofluorocarbon
HPMP	Hydrochlorofluorocarbon phase out management plans
JARN	Japan Air Conditioning, Heating & Refrigeration News
JRAIA	Japanese Refrigeration and Air Conditioning Industry Association
k	thousand
LCA	Life-cycle analysis
LCC	Life-cycle cost analysis
LFL	Lower flammability level
m	million
MEPS	Minimum energy performance standard
MSDS	Material safety data sheet

NMVOC	Non-methane volatile organic compounds
ODP	Ozone depleting potential
ODS	Ozone-depleting substance
RCC	Rated cooling capacity
SEER	Seasonal energy efficiency ratio
TFA	Trifluoroacetic acid
uHFC	unsaturated HFC
UNFCCC	United Nations Framework Convention on Climate Change
VRF	Variable refrigerant flow
CO_2e	Carbon dioxide equivalent

1 Introduction

Air conditioning systems are increasingly used worldwide to create comfort temperatures in residential and commercial buildings, but also to guarantee an optimal human performance at office work. The global market is around 105 m (million) air conditioners. With the current observed growth rates of around 10-15% in many countries, is it estimated that additional 700 m air conditioners will be added to the global stock by 2030, and 1.6 billion by 2050 (LBNL 2015).

One of the most critical issues from the excessive use of air conditioners is the negative environmental impact, primarily the climate impact caused by refrigerant emissions due to leakage (direct emissions) and the energy consumption (indirect emissions). About two-thirds of greenhouse gas (GHG) emissions are caused by energy consumption and one-third by the use of refrigerants (GIZ Proklima 2013). Future projections indicate that the emissions from the refrigeration and air conditioning sectors might contribute with 13% to the world's greenhouse gas emissions by 2030[1].

Various refrigerants are used in air conditioning systems: In developing countries hydrochlorofluorocarbons (HCFC) are still common; these substances not only contribute to global climate change but also deplete the ozone layer (GIZ Proklima 2014). Industrialised countries largely use hydrofluorocarbons (HFC) as refrigerant with a high global warming potential (GWP). This is even though alternatives are available: Direct emissions can be completely avoided by switching to natural refrigerants with a negligible GWP, and up to 50% of indirect emissions can be cut by improving product efficiency (GIZ Proklima 2013).

International agreements and various regional/national policy instruments are already implemented to reduce these negative environmental impacts. The Montreal Protocol from 1989 is effectively controlling the use of ozone depleting refrigerants, such as HCFC. Climate relevant HFCs are listed under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) and have very recently been included by the historic Kigali HFC amendment to the Montreal Protocol, aiming for a global phase-down of HFC. Besides, regions like the European Union and other countries have formulated laws restricting the use of HFC, and have introduced energy labelling schemes and Minimum Energy Performance Standards (MEPS) to reduce energy consumption from air conditioners.

Ecolabels represent another policy instrument to shift the market towards environmental friendly products and more sustainability. Ecolabels for air conditioners already exist in Asian countries (e.g. Thailand, China, South Korea). However, there is potential to formulate more ambitious award criteria, in particular considering the GWP thresholds for refrigerants. In the EU and Germany, there is currently no ecolabel for air conditioner in place, a gap which will be filled with the ecolabel "Blauer Engel".

[1] http://www.green-cooling-initiative.org/

2 Methodological framework

The study at hand follows the overall methodological structure of the Product Sustainability Assessment (PROSA) approach developed by Oeko-Institut e.V. (Grießhammer et al. 2007).

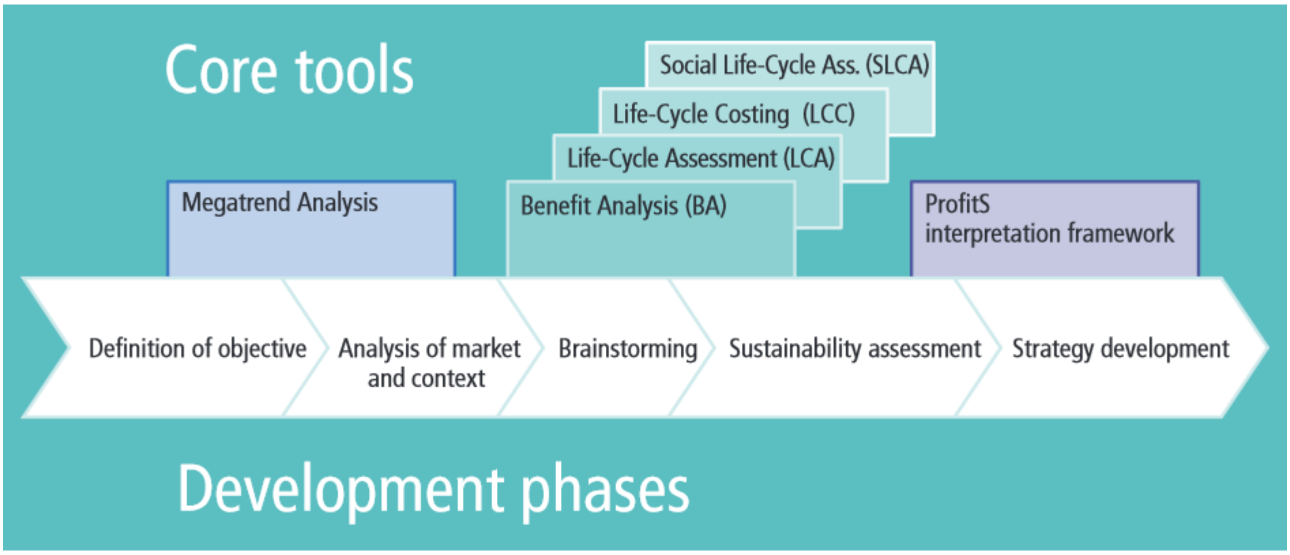
PROSA is a method for the strategic analysis and evaluation of product portfolios, products and services. The goal is to identify system innovations and options for action towards sustainable development. PROSA structures the decision-making processes that is required in this respect, reducing complexity to key elements. Important fields of application include

- strategic planning and product portfolio analysis in companies,
- product policy and dialogue processes,
- sustainable consumption and product evaluation (e.g. for derivation of eco-label criteria)
- as well as product development and marketing.

PROSA spans complete product life cycles and value chains; it assesses and evaluates the environmental, economic and (if possible) social opportunities and risks of future development trajectories. PROSA is a process-driven and iterative methodology which gives due regard to time and cost restrictions. It calls as far as possible on existing, well-established individual tools (Megatrend Analysis, Life-Cycle Assessment, Life-Cycle Costing etc.)

The following figure shows the basic structure of PROSA.

Figure 1: Basic structure of PROSA



Source: Grießhammer et al. (2007)

PROSA is an open-ended methodology that does not pre-define outcomes. It places a particular focus on the evaluation process and on interpretation frameworks. Prevailing normative disparities and conflicts among individual stakeholders, cultures and (world) regions as well as changing social values are identified clearly – as are potential approaches towards common innovation. PROSA moderates, in a targeted manner, opposing interests and decision-making situations that arise in corporate product development or in public product policy and dialogue processes.

PROSA has been used to derive eco-label criteria for numerous product groups for the Blue Angel in the past (Groeger et al. 2013). In the context of this study, the focus is set on the definition of the scope (Chapter 3), a comprehensive market and context analysis (Chapter 4), followed by technology trends (Chapter 5). Core tools for the evaluation of the product sustainability are a Life-Cycle Assessment

(LCA) combined with Life-Cycle Cost Analysis (LCC) (Chapter 6). The analysis is completed by the analysis of legislations and standards (Chapter 7) as well as a comparison of selected eco-labels (Chapter 0). Finally, the overall analysis allows for a derivation of eco-label criteria (Chapter 9).

An analysis of social impacts (e.g. Social Life-Cycle Assessment) is not part of the study.

3 Definition and scope

A great variety of different systems exists among air conditioners.

Basically there are three different categories of systems depending on the placement of the indoor unit (evaporator), the outdoor unit (condenser) as well as the number of indoor units:

Table 1: Three different categories of room air conditioning systems

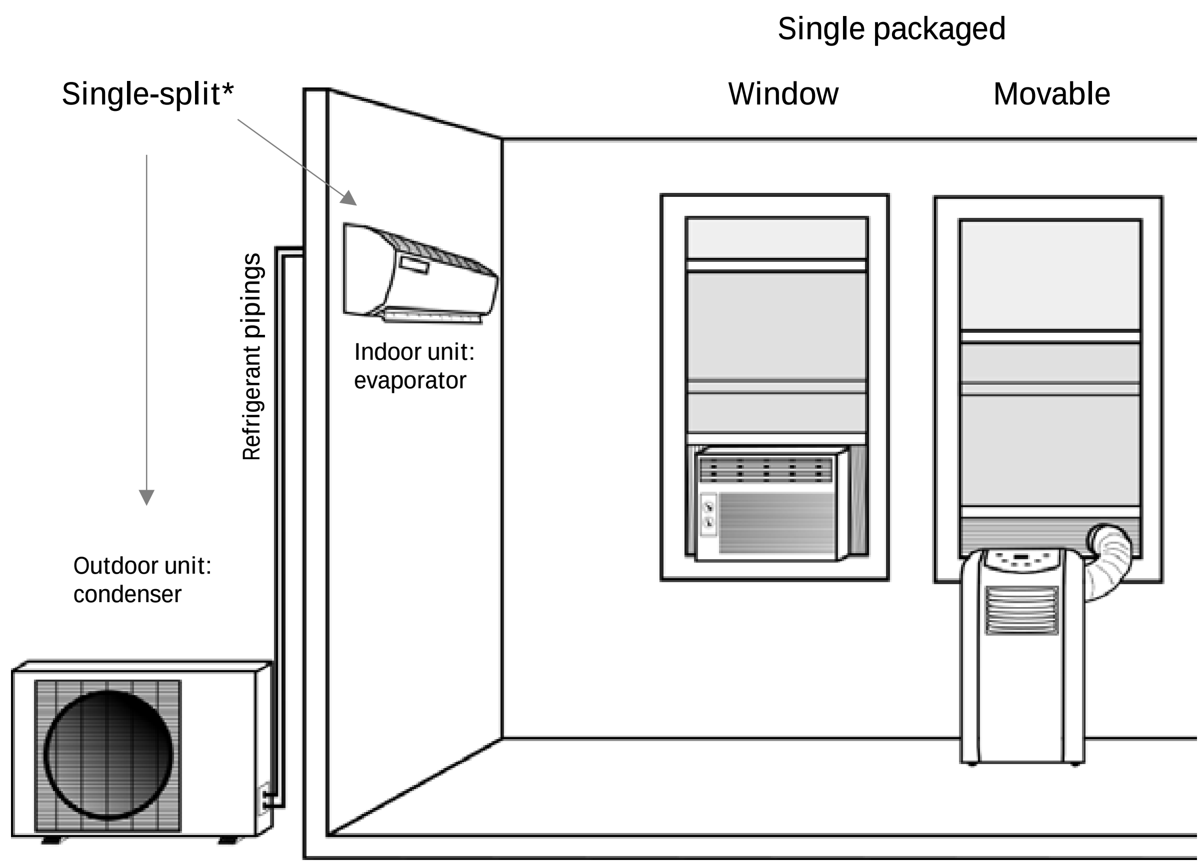
System	Location of evaporator and condenser
Single packaged air conditioner (synonyms: self-contained units, window-through-the-wall units)	Both, evaporator and condenser are within one single packaged unit located in the building to be conditioned.
Single-split air conditioner (synonyms: mono-split air conditioner, mini-split air conditioner)	The evaporator is located in the building to be conditioned, the condenser is outside the building. Both components are connected via piping.
Multi-split air conditioner and variable refrigerant flow (VRF) system	Similar to single-split air conditioner, although several indoor units are installed in different rooms to be conditioned

The product group of interest within this project are single-split air conditioners. These systems are used in both, the residential and commercial sector.

The primary function of single-split air conditioners is cooling or heating, or both. Devices that are capable of both cooling and heating are so-called reversible systems. In contrast to cooling-only devices, heating-only devices are not considered.

Possible secondary functions are the control of ventilation, humidity and air cleanliness, variable speed drive (fast cooling by overcapacity when starting; allowing part-load of the compressor instead of on-off functionality). Figure 2 shows the design of a single-split air conditioner.

Figure 2: Illustration of different room air conditioner types



*Multi-split and VRF systems function in similar fashion although more than one indoor units are connected to a condenser

Left: Single-split system with an indoor unit for cooling (evaporator) and an outdoor unit (condenser) releasing heat from the building (product group of interest within this project). Middle: window unit (single packaged system). Right: Movable air conditioner (here: single-duct) which is basically functioning in similarity to a window air conditioner), however with more degrees of freedom of adjusting the air-flow into the room.
Source: Own illustration (HEAT)

Figure 2 shows the design of a single-split air conditioner as well as other commonly found product types in the room air conditioning market. This study only covers single-split air conditioner (Figure 2, left).

The compressor can be driven by electricity or by gas. As all air conditioners in Europe are directly driven by electricity from the grid (Ecodesign Lot 10, 2008), this study focuses on single-split air conditioners that use a vapour compression cycle and are driven by grid electricity. Furthermore, the scope can be specified according to the heat transfer medium. The defined product group uses air as a heat transfer medium both at the outdoor and indoor heat exchanger. Thus, the scope of this study includes air-cooled single-split air conditioners.

The most comprehensive and appropriate definition of the focal product group is given in Regulation (EU) No 626/2011[2] (Art. 2), where an "air conditioner means a device capable of cooling or heating, or both, indoor air, using a vapour compression cycle driven by an electric compressor, including air conditioners that provide additional functionalities such as dehumidification, air-purification, ventilation or supplemental air- heating by means of electric resistance heating and appliances that may use water (either condensate water that is formed on the evaporator side or externally added water) for evaporation on the condenser, provided that the device is also able to function without the use of additional water, using air only."

In contrast to Regulation (EU) No 626/2011, we do not consider 'double duct air conditioner' and 'single duct air conditioner', as these systems are actually single packaged air conditioners (Figure 2, right) with the evaporator and condenser located in one packaged unit.

A seldom subtype of single-split air conditioners which is also covered by our definition is a non-ducted split unit with a mobile indoor evaporator, where the indoor evaporator is not mounted on the wall but movable within the room.

4 Market overview

4.1 Global situation

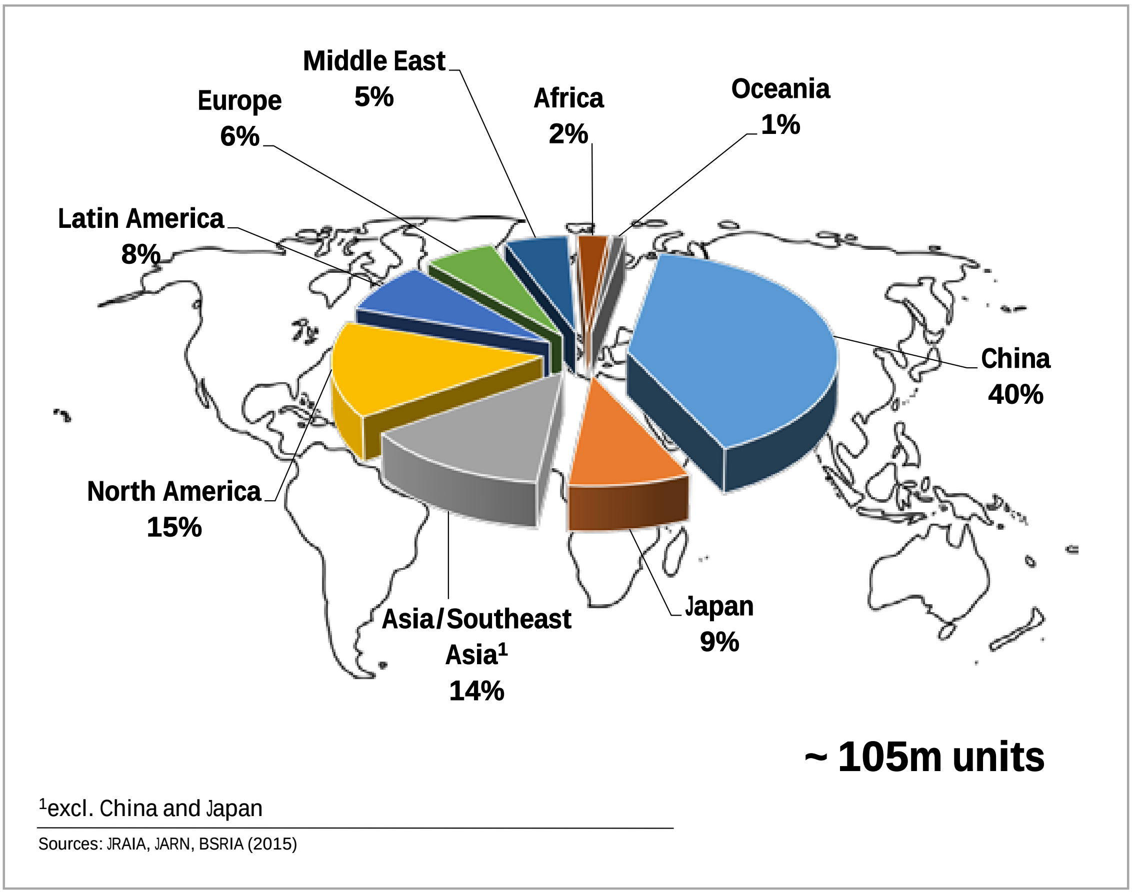
The market size for residential and commercial air conditioners accounted for approx. 105 m units in 2014, an increase from 103 m units as compared to the previous year[3]. The market value surpassed US-$ 95 billion (2014)[4]. Figure 3 provides a global overview on the demand for air conditioners broken down to different world regions in the year 2014. Major markets are found in Asia/Southeast Asia with China as the most important market in the world, followed by the Americas.

2 Commission delegated regulation (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners (OJ L 178 of 6.7.2011, p. 1)

3 JARN AC Special (2014, 2015)

4 https://www.bsria.co.uk/news/article/world-air-conditioning-market-grows-thanks-to-hot-spots/, note

Figure 3: World air conditioner demand estimate (year 2014)[5]



Source: Own illustration (HEAT), based on data from JRAIA, JARN, BSRIA (2015)

Split systems (ductless and ducted), including single and multi-split as well as VRF systems, have the largest share of the global air conditioner market with more than 85 m units in 2014[6]. From these systems, ductless single-splits – the focal group of the Blue Angel – are most prominent. These systems clearly dominate the global markets, especially in the Asian and Southeast Asian countries. With regard to other room air conditioning products, the market for window/ through-the-wall (summarised as “window” units in the following) and movable air conditioners are less important with up to 14.5 m and 2 m units in 2014, respectively[7]. Figure 4 illustrates the demand shares of single-splits, window units and movable products. The global share of ductless single-split systems is dominant, more than 80%. Movable air conditioners have notable share in some European countries, e.g., Germany but also in the United States. Regarding the split market, the U.S. is traditionally characterised by centralised

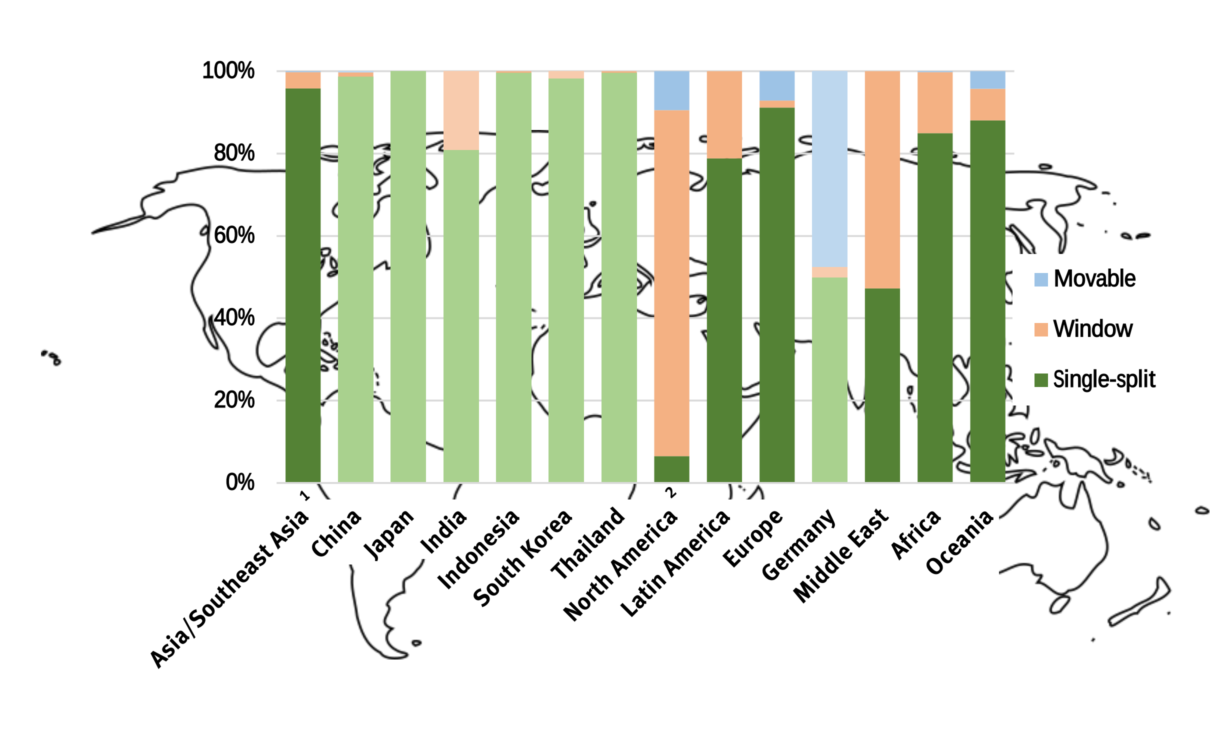
5 JRAIA (2015): http://www.jraia.or.jp/download/e-book/airacon2015/e-book_worldair.pdf; JARN AC Special (2015); BSRIA (2015): https://www.bsria.co.uk/news/article/world-air-conditioning-market-grows-thanks-to-hot-spots/: The estimate for the distribution in world demand provided here is mainly related to published JRAIA data for 2014 whereas complemented by data on movable air conditioner demand as reported by JARN and BSRIA. The demand number for China however is notably less in the JRAIA dataset than reported by JARN and BSRIA. JARN numbers have been taken for Chinese demand, ranging in the middle of JRAIA and BSRIA estimates.

6 JRAIA (2015): http://www.jraia.or.jp/download/e-book/airacon2015/e-book_worldair.pdf; JARN AC Special (2015)

7 JRAIA (2015): http://www.jraia.or.jp/download/e-book/airacon2015/e-book_worldair.pdf; BSRIA (2015): https://www.bsria.co.uk/news/article/world-air-conditioning-market-grows-thanks-to-hot-spots/

ducted systems (whole house; not integrated in Figure 4)[8] whereas ductless systems gradually gain market share in the U.S.)

Figure 4: Share of single-split systems, window and movable units in demand, 2014



Darker shadings represents regions, while brighter shadings represent countries.
Source: Own illustration (HEAT), based on data from JRAIA, JARN and BSRIA (2015).

Air conditioners in many parts of the world are not exclusive luxury goods anymore but are becoming increasingly affordable to a growing middle class. The demand grows steadily. Various countries have significant GHG emissions from refrigerant leakages but also from energy consumption of the air conditioning systems. Yet policy makers are able to counteract with appropriate legislative measures (e.g. Minimum Energy Performance Standards, MEPS) therewith enforcing technological development to improve the energy efficiency (e.g. inverter technology, see Chapter 5.2.2).

The Asian/Southeast Asian economies do not only represent the world's largest consumers (e.g., China, Japan, Indonesia, South Korea, Thailand) but also maintain the world's largest manufacturing capacities for air conditioning appliances (e.g., China, Thailand, India)[9]. China and Thailand contribute particularly to exports. The export of equipment must meet the requirements of the different markets, such as Japan, the U.S., Latin America and Europe. This implies that several production lines can be in place locally, each designated to produce for specific markets, including the domestic market. In the past Chinese manufacturers produced export units for foreign competitors, meanwhile they increasingly export products under their own brand names. International air conditioning companies have

[8] Ducted or Ductless? That is the question: http://www.ejarn.com/news.aspx?id=34212; last accessed: 12 December 2016

[9] http://www.green-cooling-initiative.org

also started to produce locally in countries with high demand in order to reduce costs regarding import tariffs, taxes etc. Table 2 indicates major (global) players active in the splits segment in Asia/Southeast Asia and country of their headquarters.

Table 2: Major manufacturers for single-split AC appliances (Asia and Southeast Asia)

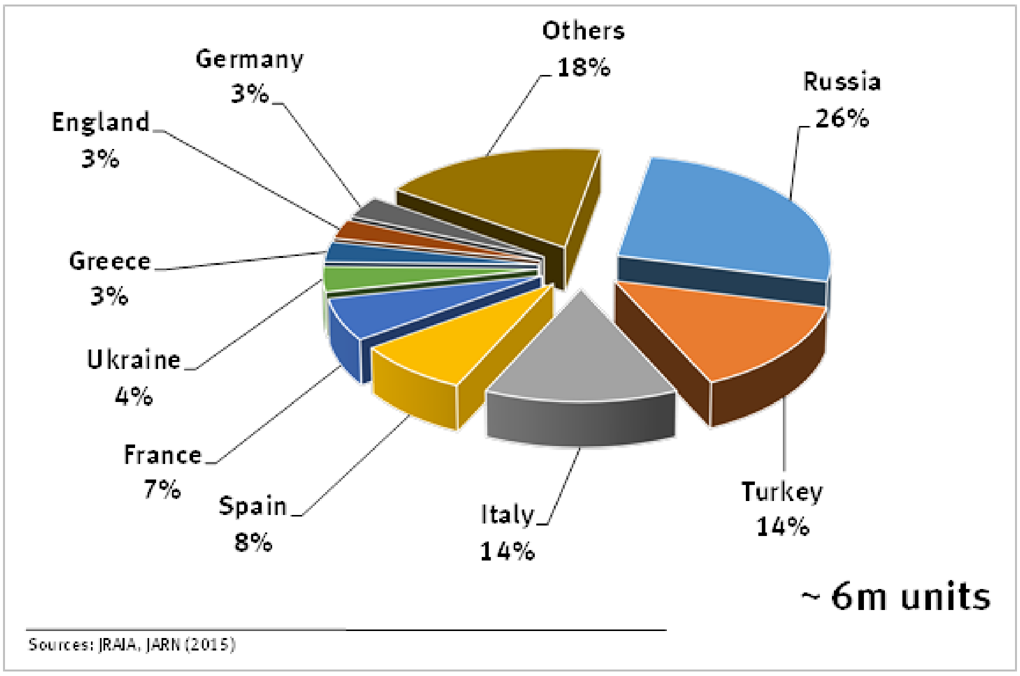
Headquarters	Manufacturer
China	Chigo, Gree, Haier, Hisense, Midea
Japan	Daikin, Fujitsu General, Hitachi Mitsubishi Electric, Mitsubishi Heavy Industries, Panasonic, Toshiba Carrier
South Korea	LG, Samsung

Source: various sources

4.1.1 Europe

The European air conditioner market can be separated into three zones due to differences in the climate. Accordingly, there is the European South, Western and North-western Europe, and North-eastern and Eastern Europe. Largest markets are Russia and Turkey. Other markets in Europe are fairly small and sales figures above 300 k (thousand) units are only found in Italy, Spain and France. Sales figures in Germany range around 200 k units per year[10] (all air conditioners, not only split types). However, these numbers have been declining notably in the past years due to slow recovery from the economic recession. A rough estimate of the European market distribution in terms of volume (around 6 m units in 2014) is shown in Figure 5.

Figure 5: Estimate for Europe's air conditioner demand (year 2014)



Available data for split and window air conditioners from JRAIA for 2014 are complemented by JARN numbers for movable air conditioners as they have notable market share in some European countries.
Source: Own illustration (HEAT), based on data from JRAIA, JARN (2015).

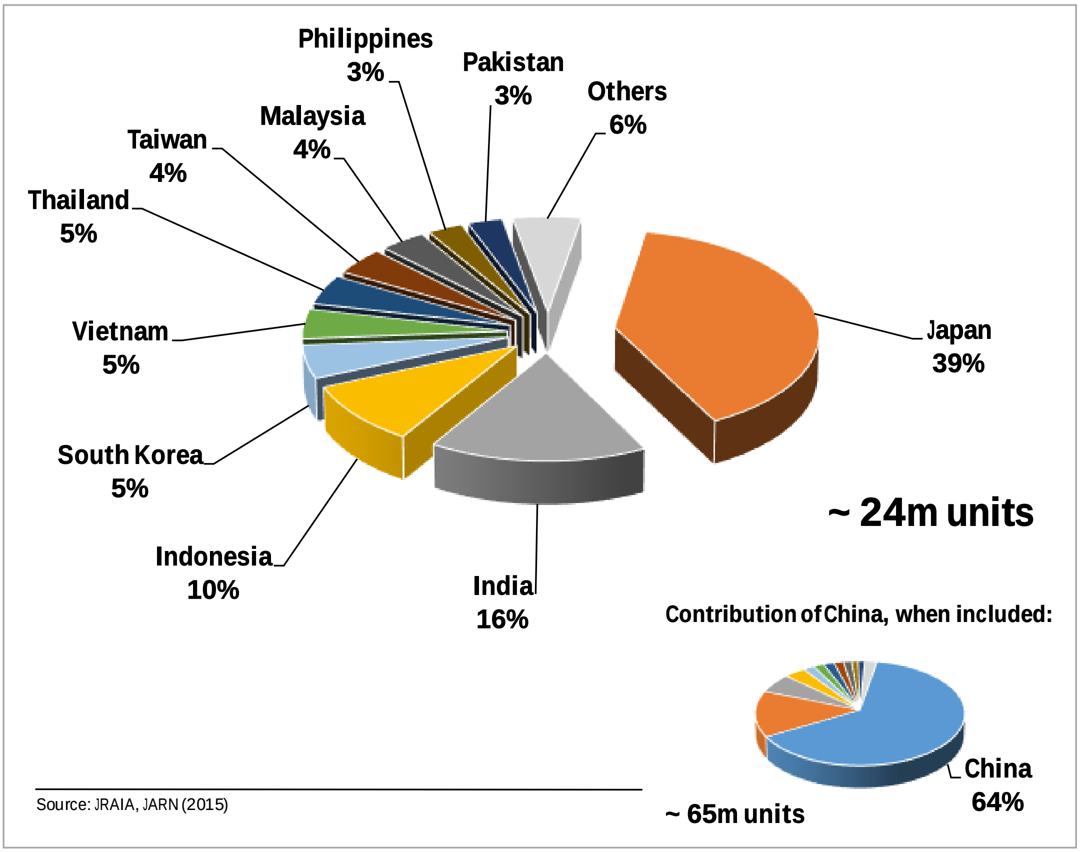
[10] JARN AC Special (2015); JRAIA (2015): http://www.jraia.or.jp/download/e-book/airacon2015/e-book_worldair.pdf

The major requested product type is split air conditioners. Still, movables have a notable market share in Europe with sales figures of around 400 k units in total. The demand for window units is even less at around 100 k units[11].

4.1.2 Asia and Southeast Asia

Asia and Southeast Asian markets are dominated by single-split appliances, except for India and the Philippines, where window-units have notable shares. Appliances in most countries are cooling-only types, due to the tropical climates. However, air conditioners with heat pump option are popular in northern regions of Asia with cold winters. Figure 6 shows the distribution of the air conditioner demand in Asia and Southeast Asia. In terms of volume, room air conditioner demand accounted for approx. 65 m units (24 m units, excluding China). After China, which is by far the most dominant player, large markets are found in Japan, India and Indonesia.

Figure 6: Estimate for air conditioner demand (year 2014) in Asia and Southeast Asia. Movable air conditioners are negligible in domestic markets of these countries[12]



Source: Own illustration (HEAT), based on data from JRAIA, JARN (2015)

[11] JRAIA (2015): http://www.jraia.or.jp/download/e-book/airacon2015/e-book_worldair.pdf

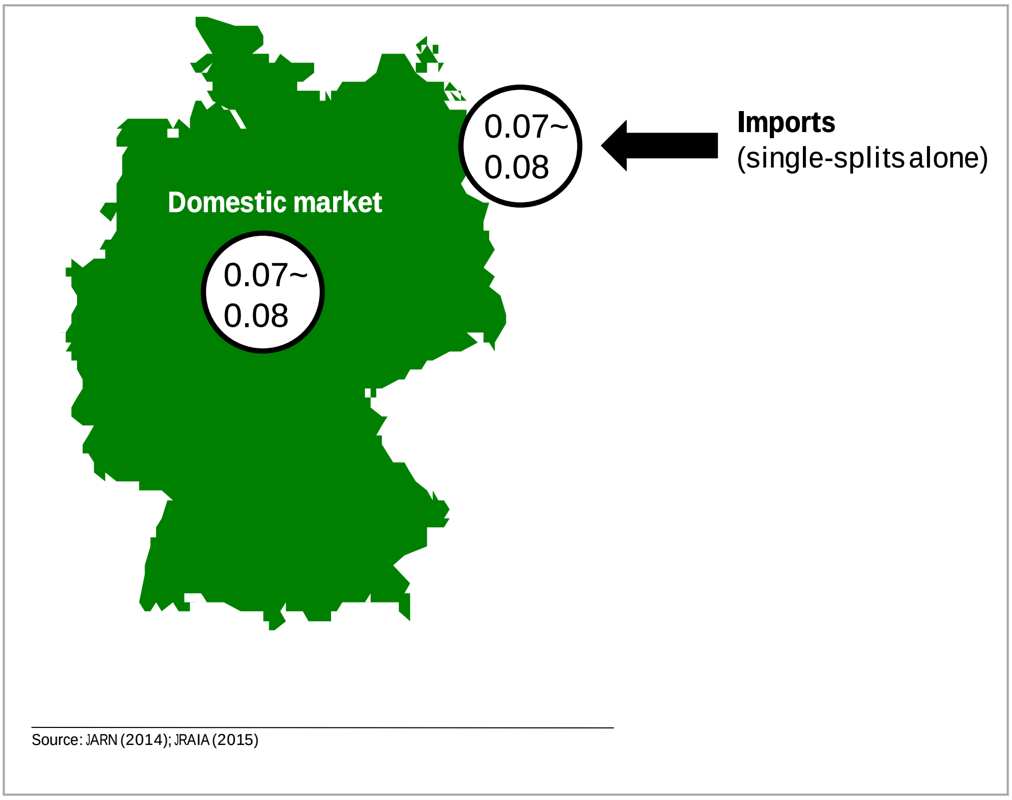
[12] The demand number for China however is notably less in the JRAIA dataset than reported by JARN and BSRIA (see also Chapter 4.3). JARN numbers have been taken for Chinese demand, ranging in the middle of JRAIA and BSRIA estimates.

4.2 Germany

4.2.1 Market size and trends

The German air conditioner market is relatively small when compared to other countries of the world, with roughly 190 k units sold per year (2012: ca. 190 k units[13]; 2013: ca. 185 k units[14]). The market value ranged around US-$ 380 million in 2014[15]. Single-split air conditioners annually contribute to the total German demand with around 70-80 k units[16]. These figures were confirmed by German air conditioning experts. Figure 7 provides the market overview for 2014. Another product group with a similar sales volume (77 k units), and fairly stable sales figures over the past years, are movable air conditioners. Window units account for only around 5 k units[17].

Figure 7: Estimated single-split market volume in million units, Germany, 2014



Source: Own illustration (HEAT), based on data from JARN (2014) and JRAIRA (2015)

4.2.2 Domestic market and market saturation

Penetration of air conditioning into households (< 5%) is much smaller in contrast to the commercial sector (penetration rate of 60%[18]). In Germany, often centralised air conditioning solutions are found, e.g. chiller or VRF-systems. However, despite the relative small market in Germany, total numbers of installations are projected to increase and to reach 2.8 million appliances by 2040 (UBA 2014). The

13 JARN AC Special (2013)
14 JARN AC Special (2014)
15 JARN AC Special (2013–2015)
16 JARN AC Special (2013, 2014); http://www.jraia.or.jp/download/e-book/airacon2015/e-book_worldair.pdf
17 JARN AC Special (2013–2015)
18 JARN AC Special (2014)

future estimates were derived by considering historical growth rates. Higher summer temperatures but also extreme hot periods during summer time (Zacharias et al. 2014) might contribute to the expected growth.

Splits sold on the German market are mostly equipped with inverters[19], a trend which is driven to a certain extent by the ErP Directive[20]. The majority of systems available on the market are also equipped with heating option[21]. Many appliances also include features such as bio-filters and air purifiers as well as technologies for air dehumidification.

4.2.3 Manufacturers and products

4.2.3.1 Manufacturers

The German market is dominated by imports, e.g. from other EU member states, China, Japan and South Korea[22]. Table 3 provides a list of dominant suppliers.

Table 3: Important suppliers in the German single-split market (2014)

Brand
Daikin
Mitsubishi Electric
Mitsubishi Heavy Industries
Midea
Fujitsu
Panasonic
Samsung
LG
Stiebel Eltron

4.2.3.2 Products

Table 4 and Table 5 provide an overview of energy-efficient products available on the German single-split market[23], with rated cooling capacities (RCCs) of approx. 2.5 kW and 3.5 kW, respectively.

Table 4: Selected energy-efficient single-split products (RCC ~2.5 kW) available in Germany

Specifications	Daikin	Mitsubishi Electric	LG	Stiebel Eltron CAWR 25	Inefficient model
Model indoor unit	FTXZ25N	MSZ-FH25VE	H09AK	ACW 25 exklusiv	
Model outdoor unit	RXZ25N	MUZ-FH25VE	H09AK	CUR 25 exklusiv	
Rank Topten.eu ≤ 3.000 kW*	2	5	6	9	
Inverter	Yes	Yes	Yes	Yes	Yes

[19] Holley BSRIA (2014), Presentation "Global Trends in Air Conditioning", Chillventa, Germany

[20] JARN AC Special (2015)

[21] Based on review of product specifications of 50 individual models (11 brands) available on the German market

[22] JARN AC Special (2014)

[23] http://www.Topten.eu; Stiftung Warentest 06/2014

Specifications	Daikin	Mitsubishi Electric	LG	Stiebel Eltron CAWR 25	Inefficient model
Cooling capacity (kW)	2.5	2.5	2.5	2.5	2.5
Heating capacity (kW)	3.6	3.2	3.2	2.4	2.0
SEER (cooling)	9.5	9.1	8.9	8.5	5.1
SCOP (heating)	5.9	5.1	5.3	4.7	3.8
Annual electricity consumption (kWh; cooling/heating)**	92/831	96/819	99/846	103/716	171/736
Refrigerant	HFC-32	HFC-410A	HFC-410A	HFC-410A	HFC-410A
Price (US-$)***	3,650	2,800	1,300	2,600	NA****

*The product information from http://www.topten.eu as of date Oct 28, 2014
** Estimate based on 350 hours cooling (~14 days) and 1400 hours heating (~58 days) per year (average climate zone)
*** 1 US-$ = 0,9183 € (Apr 2015)
**** NA: not available

Table 5: Selected energy-efficient single-split products (RCC ~3.5 kW) available in Germany

Specifications	Daikin	Toshiba	Mitsubishi Electric	Mitsubishi Electric	Inefficient model
Model indoor unit	FTXZ35N	RAS-13G2KVP-E	MSZ-FH25VE	MSZ-EF35VE (W/B/S)	-
Model outdoor unit	RXZ35N	RAS-13G2AVP-E	MSZ-FH35VE	MUZ-EF35VE	-
Rank Topten.eu ≤ 3.001-4.000 kW*	2	4	5	10	-
Inverter?	Yes	Yes	Yes	Yes	-
Cooling capacity (kW)	3.5	3.5	3.5	3.5	3.5
Heating capacity (kW)	3.0	4.0	4.0	4.0	2.6
SEER (cooling)	9.0	8.9	8.9	8.5	4.7
SCOP (heating)	5.7	5.1	5.1	4.5	3.5
Annual electricity consumption (kWh; cooling/heating)	136/1100	144/882	138/988	144/882	266/1060
Refrigerant	HFC-32	HFC-410A	HFC-410A	HFC-410A	HFC-410A

*The product information from http://www.topten.eu as of date Oct 28, 2014.
** Estimate based on 350 hours cooling (~14 days) and 1400 hours heating (~58 days) per year (average climate zone)

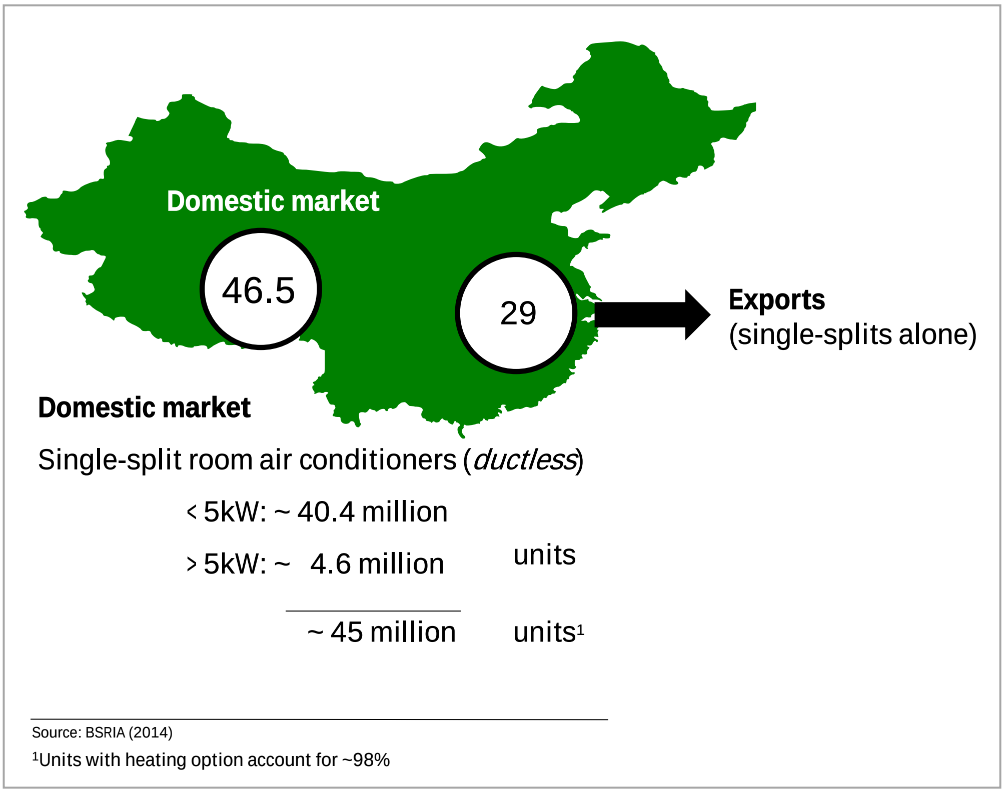
4.3 China

4.3.1 Market size and trends

China is by far the largest air conditioning player worldwide, with 80-90% of the world's total air conditioner production. Room air conditioner production has increased steadily and domestic sales have more than doubled since the mid-2000s to exceed 45 m units sold per year today[24]. Single-split systems are the most dominant product group accounting for more than 98% of domestic sales[25]. The market value for single-split appliances range in the magnitude of US-$ 23.5 billion (year 2013)[26]. Domestic sales figures and exports are given in Figure 8. The numbers within the circles refer to domestic sales figures of ducted and ductless air conditioners, unless indicated otherwise.

Within the country, the largest market is located in the eastern part with a concentration of numerous urban areas. Together with significant exports, Chinese manufacturers produce approximately 80-90 m units annually (2013/2014)[27]. The production capacities are even higher, surpassing 125 m units per annum[28]. Import numbers are negligible with around 50 k units per year[29].

Figure 8: China single-split air conditioner market 2013



Source: Own illustration (HEAT), based on data from BSRIA (2014)

24 JARN AC Special (2005); BSRIA Splits systems China report (2014)

25 BSRIA Splits systems China report (2014)

26 BSRIA Splits systems China report (2014)

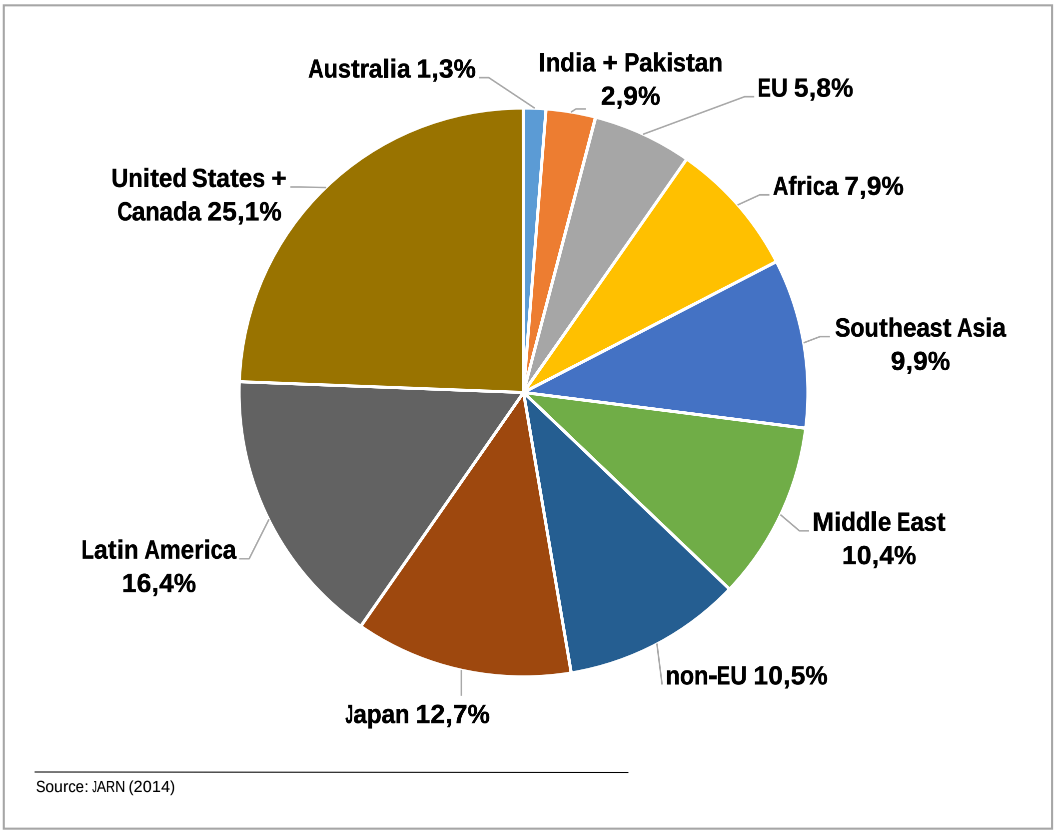
27 JARN AC Special 2014; BSRIA Splits systems China report (2014)

28 Green Cooling Initiative: www.green-cooling.org

29 BSRIA China mini-splits, windows and movables report (2007); BSRIA Splits systems China report (2014)

Air conditioners destined for export differ in their characteristics and variety as compared to the locally sold units. Whereas single-split air conditioning systems dominate the domestic market, export appliances also comprise self-contained systems such as window units and to a lesser extent, movable types. Regions/countries which import Chinese room air conditioners are given in Figure 9.

Figure 9: Percentage of Air Conditioner Exports from China 2013



Source: JARN (2014)

The figure shows the percentages from the total Chinese export. Accordingly, leading export markets are the United States, Japan, Latin America[30], the air conditioners are tailored to specific customer needs[31]. The Middle East, Southeast Asia and Africa receive less with ca. 10% of Chinese exports each.

4.3.2 Domestic market and market saturation

About 50% of Chinese households have residential air conditioning on average, similar to the commercial sector[32]. In rural areas a 20-25% ownership was observed in 2012[33]. In urban areas, a household has 1.4 air conditioners on average[34]. With this, China reveals one of the highest air conditioner penetration rates of Asia's emerging markets and in particular the inland areas catch up. Room air conditioning becomes increasingly affordable to a wider customer base. The penetration of room air

30 JARN AC Special (2014)

31 Various sources

32 BSRIA Splits systems China report (2014)

33 JARN AC Special (2013)

34 JARN AC Special (2014)

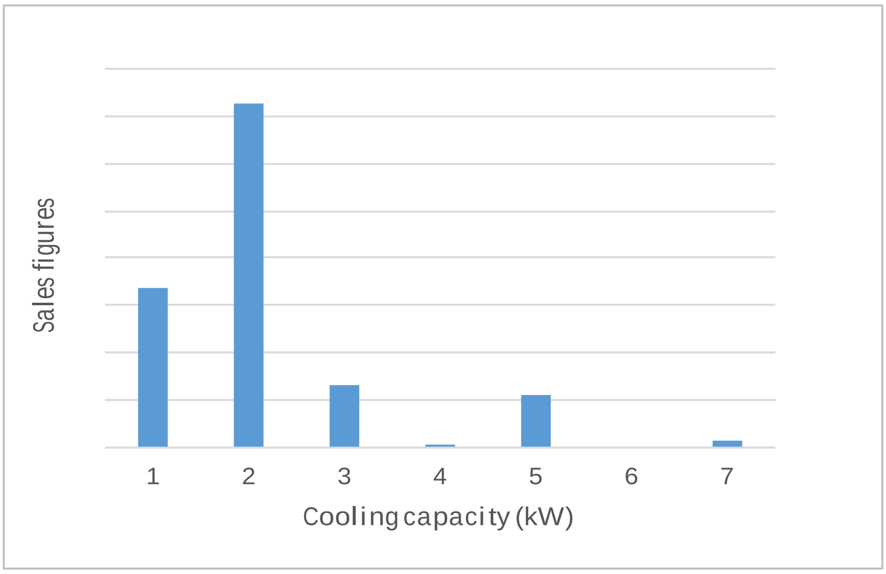
conditioning has also been promoted by the “Home Appliances to the Countryside” programme of the Chinese government which expired on January 31, 2013 after 5 years[35].

China’s market infrastructure and consumer outreach including the air conditioning sector has further diversified (E-Commerce etc.)[36]. Growth of the market was estimated around 8-9% from 2012 to 2013, also driven by sales of high-end products[37].

Preferred room air conditioners by consumers are split systems (single- and multi-splits) with cooling capacities below 5 kW (Figure 10). More than 45 m room air conditioners were sold on the domestic market in 2013 (see Figure 8). A more detailed distribution of the sold units is presented in Figure 3. The majority of the sold room air conditioners include a heat pump function, because price levels range close to those with cooling-only function. The cooling-only type is mostly found in the subtropical south-eastern part of China (ca. 1.5 m cooling only-units sold annually) with mild winters and hot summers[38].

Room air conditioners with energy-efficient inverter technology currently contribute with around 50% of annual sales figures in China[39]. The demand for this technology has significantly increased since 2008, with less than 10% share at this time. Room air conditioners with inverter technology have been incentivised through government programmes and policies[40]. It is expected that inverter technology will become a common feature in the air conditioning sector. While high investment costs represented a barrier in the past, this is negligible in view of economies of scale. For further information on inverter technology, please see Chapter 5.2.2.

Figure 10: Distribution of annual sales of air conditioning systems by the cooling capacity (China)[41]



Source: Own illustration (HEAT), based on data from CHEAA (2013)

35 http://www.chinadaily.com.cn/business/2013-01/08/content_16094148.htm
36 JARN AC Special (2014)
37 JARN AC Special (2014)
38 BSRIA Splits systems China report (2014)
39 BSRIA Splits systems China report (2014)
40 http://www.researchinchina.com/FreeReport/PdfFile/634454701549671250.pdf
41 The absence of absolute values for the y-axis is on purpose, because the focus of this figure is on the distribution of the cooling capacity and the report includes more recent sales figures.

4.3.3 Manufacturers and products

4.3.3.1 Manufacturers

Leading players in the Chinese room air conditioning market are the manufacturers Gree, Midea and Haier which have a combined estimated market share of approx. 60% in China[42], with consecutive ranking in that order (see Table 6)[43]. All three of them have together developed in-country production capacities which exceed the 100 m level and have also entered international markets[44]. The Chinese market is largely dominated by domestic manufacturers. Other mentionable Chinese single-split manufacturers are Hisense, AUX and Chigo. Leading foreign manufacturers are for instance: Japan's Daikin and Mitsubishi Electric as well as South Korea's LG. The foreign players particularly focus on the high-end segment of the market[45].

Table 6: Leading manufacturers in the Chinese single-split market (2013)

Manufacturers < 5 kW	Manufacturers > 5 kW
Gree	Gree
Midea	Midea
Haier	Haier
Hisense	Chigo
AUX	AUX
Chigo	Hisense
Panasonic	Mitsubishi Electric
Daikin	Daikin
Mitsubishi Electric	Panasonic
LG	LG
	Samsung

The ranking order is given by descending market shares.
Source: BSRIA (2015)

4.3.3.2 Products

Table 7 and Table 8 provide an overview of energy-efficient products available on the Chinese single-split market[46], with RCCs of approx. 2.5 kW and 3.5 kW, respectively.

42 JARN AC Special (2014)
43 BSRIA Splits systems China report (2014)
44 http://www.green-cooling.org
45 JARN AC Special (2014)
46 http://www.top10.cn

Table 7: Selected energy-efficient single-split products (RCC ~2.5 kW) available in China.

Specifications	Mitsubishi	Haier	Midea	Panasonic	Inefficient model
Model	MSZ-PZHJ09VA	KFR-26GW/05 SDA21A	KFR-26GW/ BP3DN1Y-B201(A1)	KFR-26GW/ BpHH1	-
Rank Top10 China "≤ 2.800 kW"*	1	4	6	9	-
Inverter	Yes	Yes	Yes	Yes	Yes
Cooling capacity (kW)	2.60	2.60	2.60	2.60	2.50
Heating capacity (kW)	3.65	4.00	4.20	3.50	3.20
SEER (Wh/Wh)	5.45	4.80	4.77	4.66	3.68
Seasonal electricity consumption (kWh; cooling/heating)	269/187	295/222	293/227	316/218	380/270
Refrigerant	HFC-410A	HFC-410A	HFC-410A	HFC-410A	NA**
Price (US-$)***	1520	680	710	970	NA**

*The product information from http://www.top10.cn as of date Mar 2, 2015
** NA: Not available
*** 1 US-$ = 6.20 RMB (Apr 2014)

Table 8: Selected energy-efficient single-split products (RCC ~3.5 kW) available in China.

Specifications	Mitsubishi	Midea	Daikin	Panasonic	Inefficient model
Model	MSZ-PZHJ12VA	KFR-35GW / BP3DN1Y-HB201(A1)	FTXF135NC-W	KFR-36GW / BpHH1	-
Rank Top10 China "2.801 - 4.500 kW"*	1	4	8	11	-
Inverter?	Yes	Yes	Yes	Yes	Yes
Cooling capacity (kW)	3.60	3.50	3.50	3.60	3.20
Heating capacity (kW)	4.50	4.40	4.20	4.50	4.10
SEER (Wh/Wh)	4.80	4.73	4.65	4.62	3.50
Seasonal electricity consumption (kWh; cooling/heating)	414/301	391/315	415/300	431/312	484/376
Refrigerant	HFC-410A	HFC-410A	HFC-410A	HFC-410A	NA**
Price (US-$)***	1160	920	870	970	NA**

*The product information from http://www.top10.cn as of date Mar 2, 2015
** NA: Not available
*** 1 US-$ = 6.20 RMB (Apr 2014)

4.4 India

4.4.1 Market size and trends

Despite its large population and hot climate, the Indian air conditioner market did not reach its expected potential in the past. However, over the last 10 years, sales figures of air conditioners have been growing and almost tripled[47]. In 2014, around 3.8 m air conditioning units have been sold on the domestic market (all air conditioners, not only split types). Single-split air conditioners have continuously gained market share in the past, now notably exceeding window-types (movables are negligible). The current share of single-split air conditioners has reached 80% of total sales in 2013[48] and 2014[49]. Main reasons for a growing market are increased wealth and income of the Indian population. Generally, air conditioners are relatively cheap in India in comparison to other countries since Indian consumers tend to keep a sensitive view on prices. Cheap air conditioners are top-runners[50]. Market value for single-splits is estimated around US-$ 1.4 billion in 2014[51].

While import numbers accounted for about 50% in 2008[52] in 2014, this number has declined to ca. 20%. Within this period, local production increased with improved supply chains and decreasing imports from China. Current production capacities are in the magnitude of presumably 10 m units. Market growth in the past has been behind expectations, thus surplus capacities could reflect these circumstances[53]. While 1.5 m single-split air conditioners were produced in 2008, almost 3 m units have been produced in 2014[54]. Figure 11 gives a more detailed overview about the 2014 splits market in India.

47 BSRIA, JARN, JRAIA

48 JARN AC Special (2014)

49 JARN AC Special (2015)

50 JARN AC Special (2015)

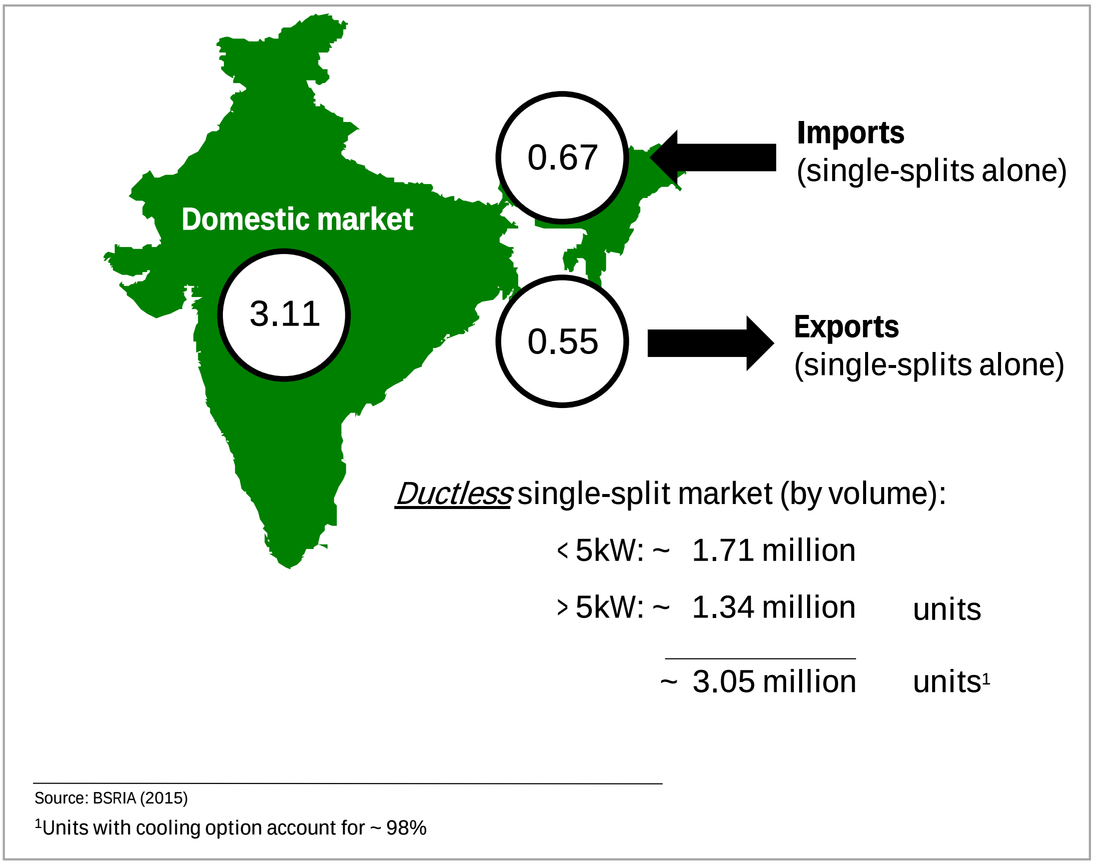
51 BSRIA India splits systems report (2015)

52 BSRIA Air conditioning report Middle East, Africa and Indian Subcontinent (2009)

53 http://www.green-cooling-initiative.org

54 BSRIA Air conditioning report Middle East, Africa and Indian Subcontinent (2009), BSRIA India splits systems report (2015)

Figure 11: Single-split air conditioner market, India, 2014



Source: Own illustration (HEAT), based on data from BSRIA (2015)

4.4.2 Domestic market and market saturation

The penetration rate of air conditioning into households is fairly low with less than 5% in 2013/2014[55]. The commercial sector reveals higher rates with more than 70% (2014). The majority of sold ductless single-splits are cooling-only types; only a small fraction has a heat pump option (reversible-type). However, the reversible systems are slowly picking up growth in the North of India. While in 2008 appliances with a cooling capacity of > 5 kW accounted for ~80% of the market, now demand of appliances with < 5 kW have come to a share of more than half of the ductless single-splits sold on the Indian market. Multi-splits are not popular and installation of several single-splits is a cheaper option. Consumers still tend to buy and install several single-split systems, also inside big buildings (2008; 2014[56]). Inverter air conditioners still are of minor importance but show significant growth rates with 25% in 2013/2014. The process is also driven by policy makers with increasingly stringent MEPS.[57]

[55] JARN AC Special (2014); BSRIA split systems India (2015)

[56] JARN, BSRIA (2008, 2015)

[57] JARN AC Special (2015)

4.4.3 Manufacturers and products

4.4.3.1 Manufacturers

Chinese manufacturers have a small share on the Indian market, whereas Japanese and Korean manufacturers exist in a competitive environment. The Indian market is split among more than 25 players. Local manufacturers in India are often importing components such as compressors to produce air conditioner (e.g. from Thailand or China)[58]. Table 9 shows the leading brands and manufacturers in India.

Table 9: Leading brands and manufacturers in the Indian single-split market (2014)

Brand < 5 kW	Brand > 5 kW
Market share > 85%	
Voltas	LG
LG	Voltas
Samsung	Samsung
Blue Star	Daikin
Daikin	Blue Star
Hitachi	Hitachi
Panasonic	Panasonic
Toshiba	Toshiba
Carrier	Carrier
Godrej	Godrej
Onida	Onida
Market share < 15%	
Lloyd	General
General	Lloyd
Whirlpool	Sharp
Electrolux	Mitsubishi Electric
Videocon	Whirlpool
Others	Others

The ranking order is given by their descending market share.
Source: BSRIA (2015).

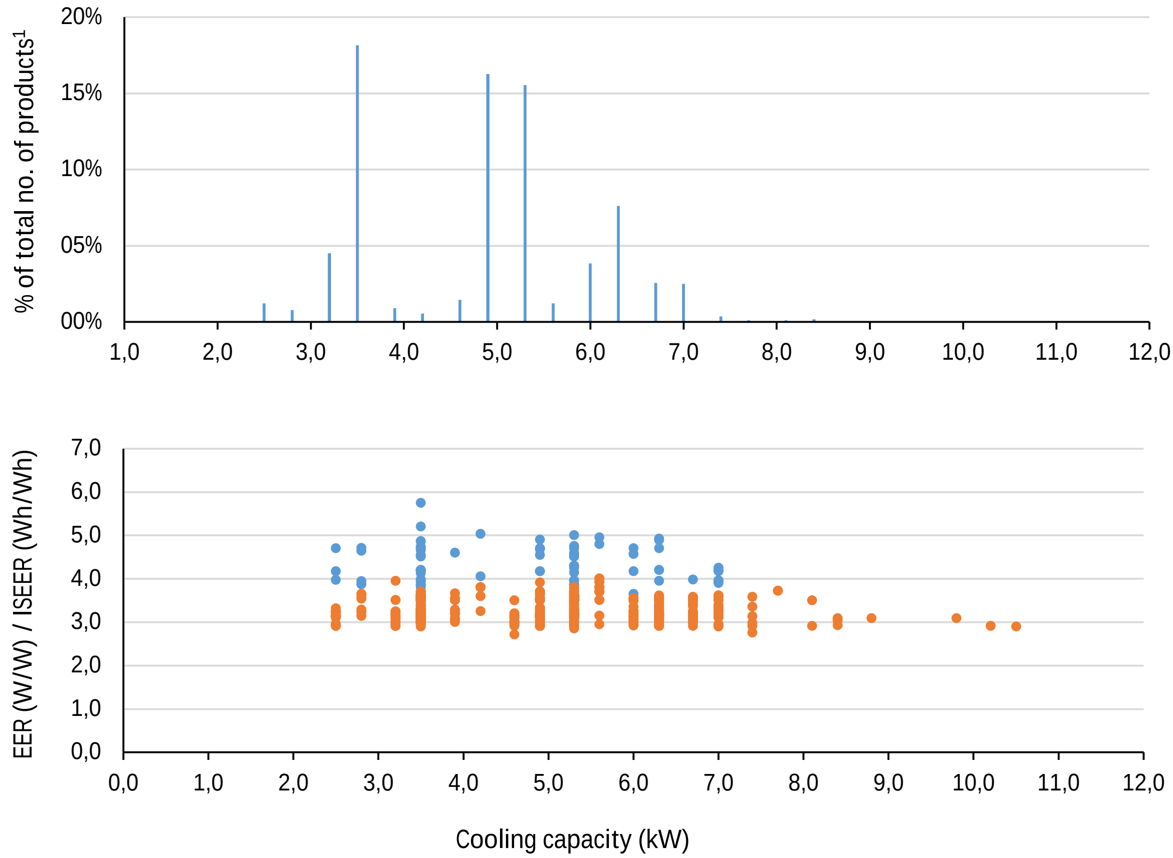
4.4.3.2 Products

The Indian Bureau of Energy Efficiency provides a database which contains information on key parameters for variable and non-variable single-split air conditioners. The majority of products have a cooling capacity between 3 kW and 7 kW (Figure 12). Products below 5 kW account for less than

[58] JARN AC Special (2014)

45%[59]. Large-capacity units are extremely rare, compared with markets from Thailand and South Korea. Inverter share on products below 5.3 kW is around 6% and only slightly higher for units with cooling capacities above 5.3 kW (7%).

Figure 12: Distribution of room air conditioning products on the Indian domestic market by cooling capacity and energy efficiency



Source: Bureai of Energy Efficiency, India

¹Total number of products: 1641

Source: based on data from Bureau of Energy Efficiency, India. Units with inverter-based technology are displayed in blue (with corresponding SEER values) and on/off units in orange (with corresponding EER values)

Table 10 (~3.5 kW), Table 11 (~5 kW) and Table 12 (~7 kW) provide an overview of available products on the Indian single-split market, depending on the cooling capacity.

59 Please note that still more units smaller 5 kW cooling capacity are sold on the market.

Table 10: Selected energy-efficient single-split products (RCC: ~3.5 kW) available in India

Specifications	Hitachi	Sharp	Haier	LG	Godrej
Model	RAU012HVEA	AH-XP10LV	HSU-12HQAB (R2DB)	BS-Q126B8R8	GSC 12 FG 6 BNG
Ranking bijlibachao.com blog ≤ 1RT; ≤ 3.5 kW	1	4	8	10	-
Inverter?	Yes	Yes	Yes	Yes	No
Cooling capacity (kW)	3.56	2.81	3.50	3.40	3.38
Heating capacity (kW)	-	-	-	-	-
EER	4.00	3.82	3.54	3.47	3.70[60]
Power consumption (W)	890	945	990	1320	912
Refrigerant	HFC-410A	HFC-410A	HFC-410A	HFC-410A	R-290
Price (US-$)**	770	440	630	620	690

*The product information from http://www.bijlibachao.com as of date Jun 5, 2015
** 1 US-$ = 62.89 INR (Apr 2015)

Table 11: Selected energy-efficient single-split products (RCC ~5.3 kW) available in India

Specifications	Hitachi	Hitachi	Sharp	Carrier	Godrej
Model	RAU014CVEA	RAU019CVEA	AH-XP18PHT	Kurve Inverter (1.5T)	GSC 18 FG 6 BOG
Rank bijlibachao.com blog "≤ 1.5RT; ≤ 5.3 kW"	1	4	8	10	-
Inverter?	Yes	Yes	Yes	Yes	No
Cooling capacity (kW)*	4.2	5.5	5.3	5.3	5.00
Heating capacity (kW)	-	-	-	-	-
EER	4.00	3.83	3.66	3.57	3.70
Power consumption (W)	1045	1448	1440	1478	1351
Refrigerant	HFC-410A	HFC-410A	HFC-410A	HCFC-22	R-290
Price (US-$)**	790	890	690	690	770

*The product information from http://www.bijlibachao.com as of date Jun 5, 2015
** 1 US-$ = 62.89 INR (Apr 2015)

60 In an interview with Godrej an EER of 3.9 was mentioned, but not given in product specifications (interview available: http://www.hydrocarbons21.com/articles/6286/godrej_forging_new_pathways_for_hydrocarbons_in_india_and_beyond)

Table 12: Selected energy-efficient single-split products (RCC ~7 kW) available in India

Specifications	Carrier	Hitachi	Carrier	Panasonic
Model	Superia Plus K+ (2.0T)	RAU023EUEA	Kurve Inverter (2.0T)	CS-S24RKY
Rank bijlibachao.com blog "≤ 2RT; ≤ 7.03 kW"	1	4	8	10
Inverter?	Yes	Yes	Yes	Yes
Cooling capacity (kW)*	7.0	6.8	7.0	6.0
Heating capacity (kW)	-	-	-	-
EER	3.61	3.55	3.48	3.30
Power consumption (W)	1947	1930	2020	1820
Refrigerant	HFC-410A	HFC-410A	HCFC-22	HCFC-410A
Price (US-$)**	960	940	880	1080

*The product information from http://www.bijlibachao.com as of date Jun 5, 2015
** 1 US-$ = 62.89 INR (Apr 2015)

4.5 Thailand

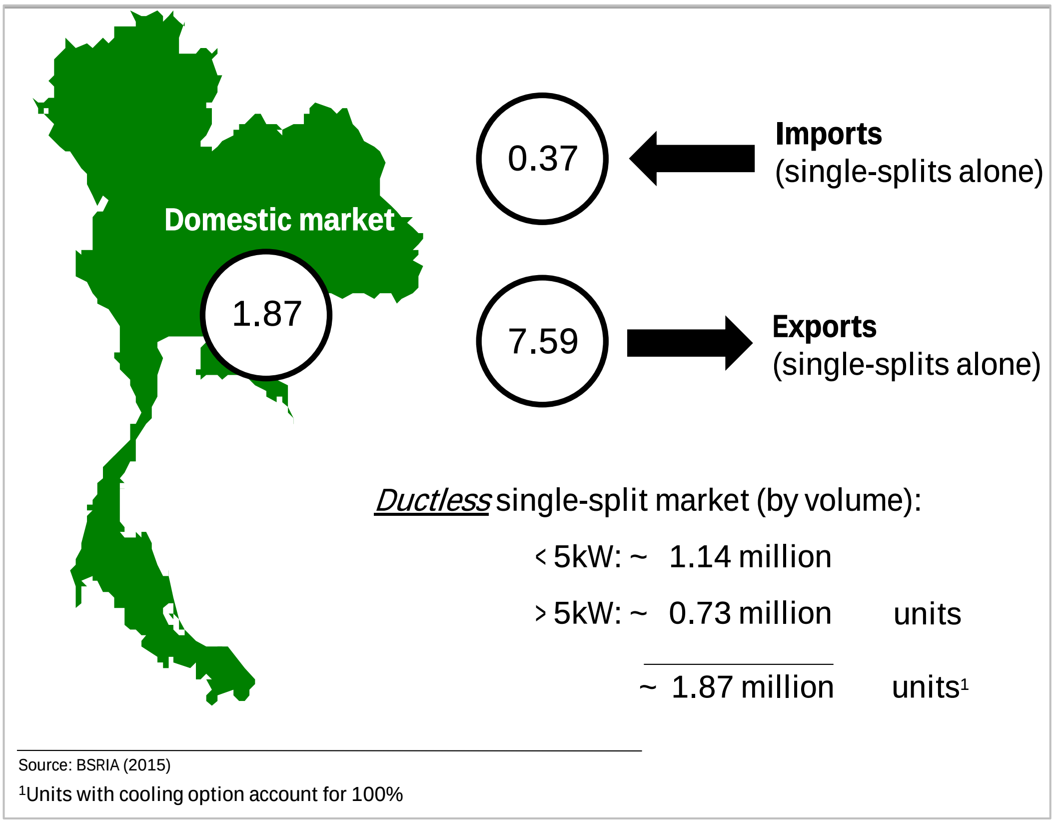
4.5.1 Market size and trends

In contrast to its domestic market, single splits produced for export outweigh by a factor of 4 (in 2014). While more than 1.8 m were sold domestically in 2014, more than 7.5 m units were shipped outside the country (Figure 13). The domestic market accounted for a market value of around 830 m US-$. Sales have doubled in the past 10 years whereas 50% of the appliances were sold from 2011 to 2014[61]. As is the case with China, factories may have specialised divisions which produce for given overseas markets. Both countries are the major export hubs in Asia. Thai split production ranged around 9.1 m units in 2014. Penetration of air conditioning is high in both the residential and commercial sector with more than 60%[62].

[61] JARN AC Special (2006–2015)

[62] BSRIA (2015) Thailand splits systems report

Figure 13: Single-split air conditioner market, Thailand, 2014



Source: Own illustration (HEAT), based on data from BSRIA (2015)

4.5.2 Domestic market and market saturation

Slightly more small products (cooling capacity < 5 kW) are sold on the domestic market than big units (cooling capacity > 5 kW). Cooling-only ductless single splits form the entirety of the market and heating option is not found. Inverter penetration was 16% for room air conditioners in 2014 and is rising[63].

4.5.3 Manufacturers and products

4.5.3.1 Manufacturers

The Thai market for ductless split air conditioners is dominated by Japanese and Korean manufacturers. Among them, Mitsubishi Electric had a market share of 30% in 2014 (Samsung 20%, LG and Daikin 18%) and is the market leader since many years[64]. Mitsubishi Electric manufactures about 3 m units on an annual basis for Thai and overseas markets. Haier is the only Chinese manufacturer with higher market share (Table 13). Apart from Panasonic and Hitachi, all key Japanese manufacturers have production bases in Thailand. Japanese manufacturers are focusing on placing high-end inverter air conditioners on the market. A number of local manufacturers exist aside of the major Asian players which are mainly producing models in the low price segment (Table 14). Thai producer Saijo Denki has been awarded several times in recent years for its energy-efficient products and is also active in expanding to overseas markets such as Singapore.

[63] JARN AC Special (2015)

[64] JARN AC Special (2015)

Table 13: Leading manufacturers and brands in the Thai single-split market (2014)

Brand < 5 kW	Brand > 5 kW
Market share > 85 %	
Mitsubishi Electric	Mitsubishi Electric
Samsung	Samsung
LG	Daikin
Daikin	LG
Panasonic	Panasonic
MHI	MHI
Haier	Toshiba Carrier
Hitachi	Haier
Trane	Trane
York	York
Market share < 15 %	
Toshiba Carrier	Hitachi
Fujitsu	Uni Aire
Uni Aire	Fujitsu
Hyundai	Hyundai
Others	Others

The ranking order is given by their descending market share.
Source: BSRIA (2015).

Table 14: Thai manufacturers and brands (alphabetical order)

Brand < 5 kW
Central Air
Daisenko
Eminent
Mitsui
Saijo Denki
Star-Aire
Tasaki
Uni-Aire
Unico (Amena)

Source: BSRIA (2015)

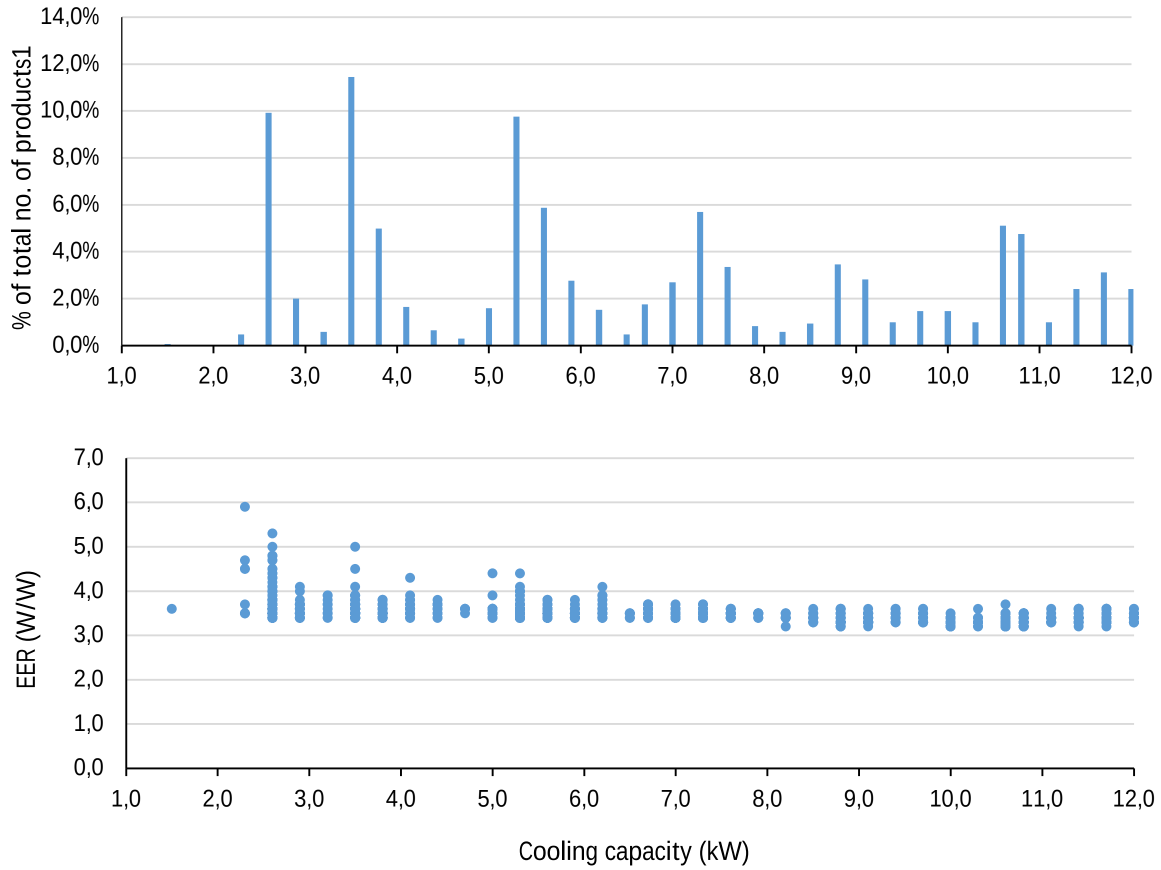
4.5.3.2 Products

The distribution of Thai products with the label number 5 (EGAT) and the corresponding energy efficiencies are displayed in Figure 14, regarding a range of cooling capacities.

There are more units on the market with smaller capacities (< 6 kW) but the entire range up to 12 kW is represented. Products up to 5.3 kW make up 40%.

Especially low to mid-capacity units show highest efficiencies. The share of inverter products on these units is about 26%[65]. Units above 5.3 kW have a significantly lower share on inverter products with about 9%.

Figure 14: Distribution of room air conditioning products on the Thai domestic market by cooling capacity and energy efficiency



Source: EGAT 5, Thailand

[1]Total number of products: 1701

Source: Based on data from the Thailand Environment Institute and EGAT

A number of selected high-end energy-efficient room air conditioners including the most important performance parameters are provided in Table 15 (≤ 5.3 kW) and Table 16 (> 5.3 kW to 12 kW).

65 Please note that this share refers to products and differs from the penetration rate of inverter technology.

Table 15: Selected energy-efficient single-split products ≤ 5.3 kW available in Thailand

Specifications	Daikin	Mitsubishi Electric	Samsung	Daikin	Median
Model	FTXZ09NV1S	MSZ-FK09VA-T1	AR10HVSDLWK	FTKS09HV2S	
Inverter?	Yes	Yes	Yes	Yes	
Cooling capacity (kW)*	2.3	2.6	2.6	2.3	3.5
Heating capacity (kW)	-	-	-	-	-
EER (W/W)	5.9	4.8	4.8	4.7	3.5
Power consumption (W)	390	540	540	490	1,000
Annual energy consumption (kWh/a)	1,238	1,596	1,552	1,515	3,030
Refrigerant	R-410A	R-410A	R-410A	R-410A	
Price (US-$)**	1,650	990	720	660	

* Cooling capacities converted to kW from BTU/hr
** 1 US-$ = THB 35.5863 (Dec 2015)
Data source: Thailand Environment Institute and EGAT

Table 16: Selected energy-efficient single-split products > 5.3 kW up to 12 kW available in Thailand

Specifications	Daikin	Samsung	Saijo Denki	LG	Median
Model	FTKM24NV2S	AR24HVFSQUR	SSC-18A-A-STGP1/SOR-18A-A-STGP1	I18B	
Inverter?	Yes	Yes	Yes	Yes	
Cooling capacity (kW)*	6.2	6.2	5.6	5.6	8.8
Heating capacity (kW)	-	-	-	-	-
EER (W/W)	4.1	3.9	3.8	3.8	3.4
Power consumption (W)	1,510	1,590	1,470	1,470	2,590
Annual energy consumption (kWh/a)	4,340	4,670	4,410	4,200	7,700
Refrigerant	R-410A	R-410A	R-410A	R-410A	

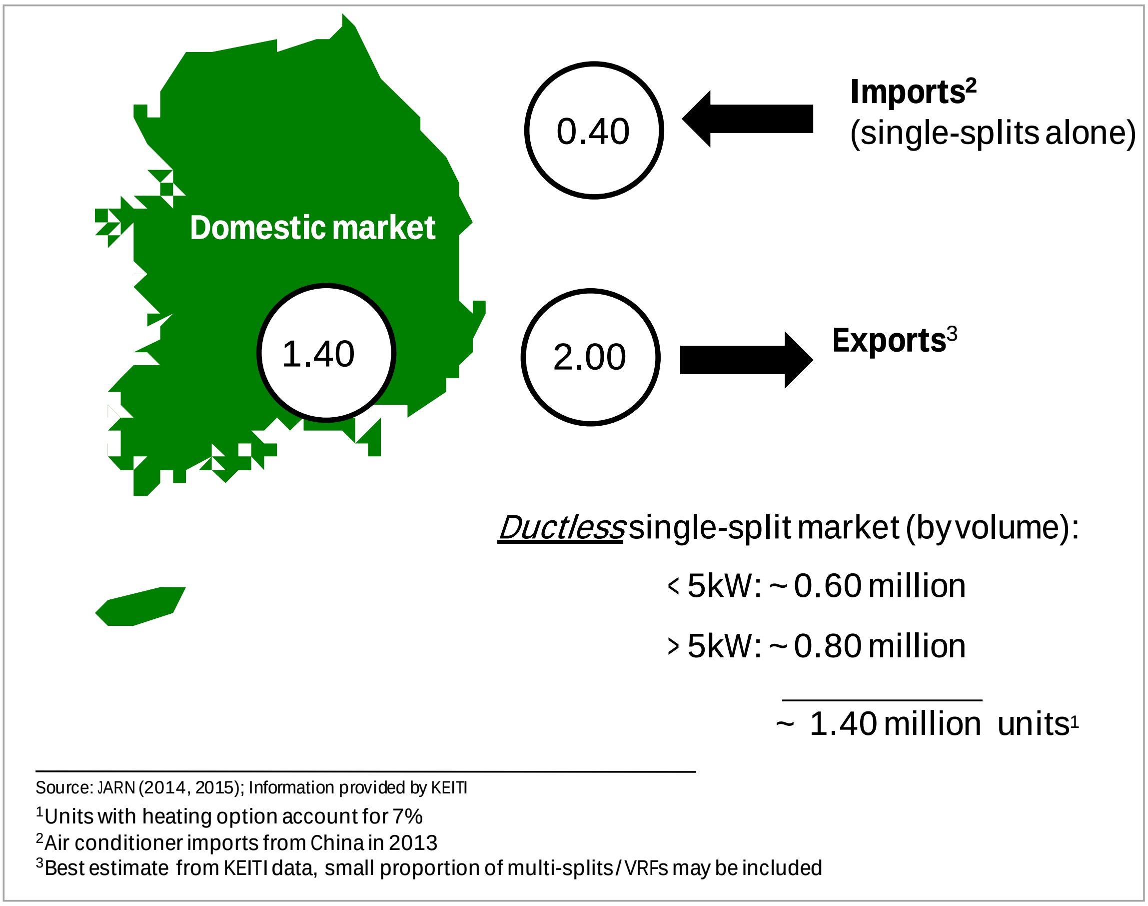
* Cooling capacities converted to kW from BTU/hr
Data source: Thailand Environment Institute and EGAT

4.6 South Korea

4.6.1 Market size and trends

The room air-conditioning market shows a unique feature, because mid- and high capacities play a significant role. They are used mostly for commercial purposes and are represented by floor-standing (majority) and ceiling-suspended indoor units, also called PACs or “packaged air conditioners”. Low-capacity units are dominated by wall-mounted units. Sales figures (year 2014) are given with 1.4 m units (Figure 15), whereby PACs account for approx. 0.8 m units (see also Chapter 4.6.3.2)[66]. Imports are around 0.4 m units and exports in the magnitude of 2 m units. The total air conditioner production in the country is close to 3 m units per year[67].

Figure 15: Single-split air conditioner market, South Korea, 2014



Source: Own illustration (HEAT), based on data from JARN (2014, 2015), KEITI (personal information)

4.6.2 Domestic market and market saturation

Korean consumers prefer domestic products and the market seems to be protective. The air conditioner penetration rate is around 70%. The share of inverter units on total sales is about 35% for lower capacity units and about 95% for lager “packaged air conditioners” [68]. Reversible units account for 7% regarding the total sales figures. Koreans are commonly heating their houses with hot-water floor

66 JARN AC Special (2015): http://www.ejarn.com/news.aspx?ID=34795

67 Information provided by KEITI

68 JARN AC Special (2015)

system, called *ondol*. Gas-driven air conditioners are currently gaining dominance due to energy shortages and the price advantages of gas over electricity.

4.6.3 Manufacturers and products

4.6.3.1 Manufacturers

Samsung and LG are dominating the South Korean domestic market with 80% market share. These players also have higher market shares in other countries (see also Table 9 and Table 13). The main Korean players as well as other Korean manufacturers and brands are listed in Table 17.

Table 17: South Korean manufacturers and brands (alphabetical order)

Brand
CLK Corporation
Dayou Winia
LG
Samsung
Their market share: ~ 90% (brands mentioned above)

4.6.3.2 Products

In South Korea, room air conditioners with cooling capacities above 5 kW have a significantly higher share as compared to other markets. Figure 16 illustrates the distribution of available products in relation to the cooling capacity. Similar, the range of energy efficiencies is presented. The analysis is based on a dataset provided by KEITI, with product information of 1518 units; 1356 units had less than 12 kW of cooling capacity. These products are also covered by the existing labelling scheme, and have been registered between 2013 and 2015. Smaller units (up to 5.2 kW) only make up 21% of the available product range, whereas the majority of products have cooling capacities higher than 5.2 kW. A dominance of products (50%) is particularly observed in the range 6 kW to 7.2 kW cooling capacity.

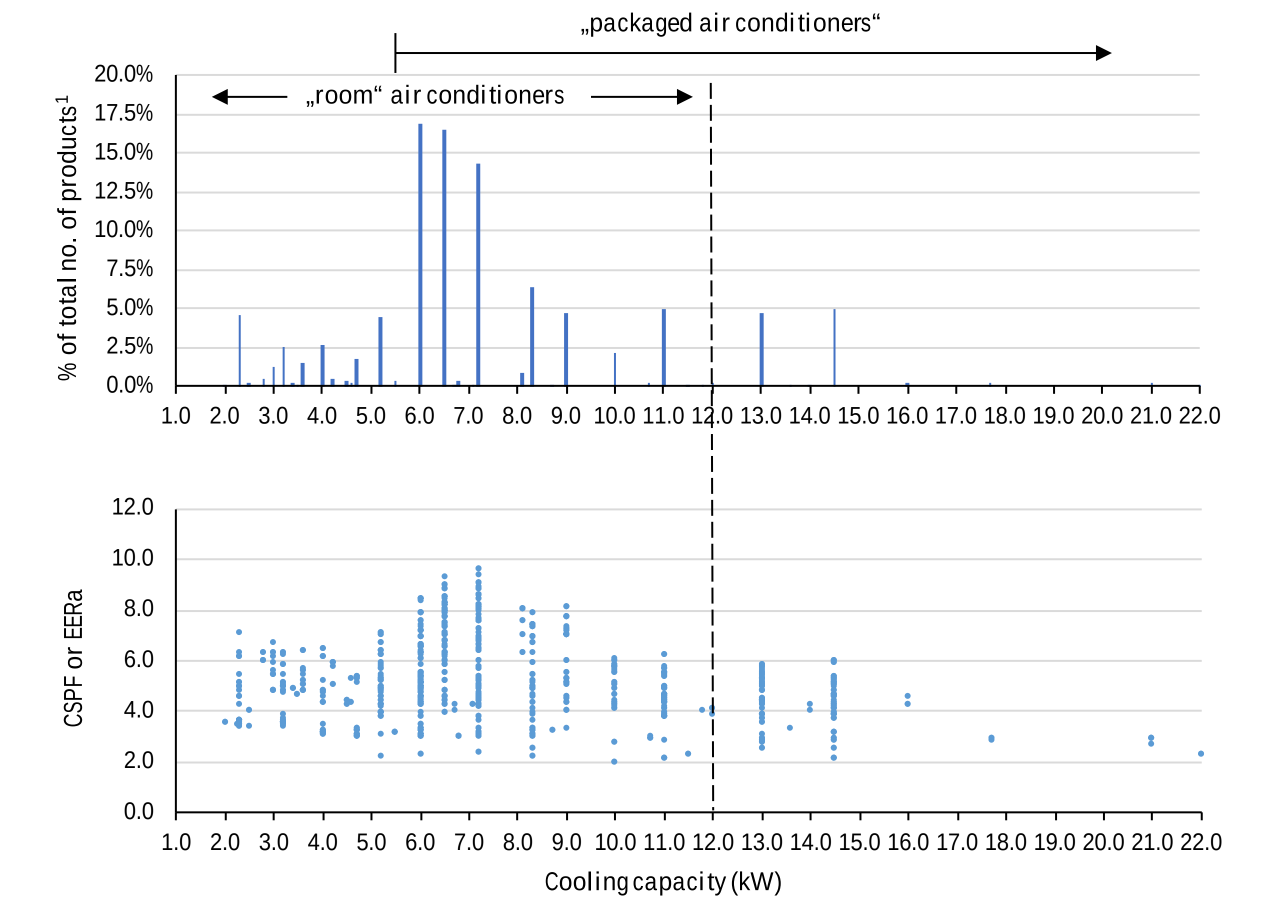
For products with less than 12 kW cooling capacity, the units with heating option account for around 28% (33% up to 22 kW cooling capacity)[69]. Also, the market does not exclusively consist of inverter units.

An analysis of smaller units (≤ 5.2 kW), where sufficient information was available, showed that 44% of the units had inverter technology, while much higher shares (90%) were found for large units (5.2 to 12 kW). These numbers correspond to those reported for the inverter share on domestic sales.

Interestingly, the highest efficiency level is found for medium size products with cooling capacities around 7 kW. This is in contrast with products on the European market, where smaller units show the highest energy efficiency (see Chapter 5.2.2).

69 Please note that this share refers to products, not sales figures.

Figure 16: Distribution of room air conditioners on the South Korean domestic market by cooling capacity and energy efficiency



Source: KEITI, South Korea

[1]Total number of products: 1518 (33% equipped with heating option)

Source: Own illustration (HEAT); data source: KEITI (2016)

A number of selected high-end energy-efficient room air conditioners including the most important performance parameters are provided in Table 18 (≤ 5.2 kW) and Table 19 (5.2 kW to 12 kW). Samsung and LG provide the top-efficient products.

Table 18: Selected energy-efficient single-split air conditioner ≤ 5.2 kW cooling capacity, available in South Korea

Specifications	Samsung	LG	Samsung	LG	Median
Model	AR06HVAF1WK	SNQ071BS1W/S UQ071SA	AR10HVAD1W K	SNQ090BS1W/S UQ090SA	
Inverter?	Yes	Yes	Yes	Yes	NA
Cooling capacity (kW)	2.3	3.0	4.0	3.6	3.6
Heating capacity (kW)	-	-	-	-	-
CSPF or EERa	7.11	6.71	6.43	6.36	4.42
Annual energy consumption (kWh/a)	105	145	202	184	293

Specifications	Samsung	LG	Samsung	LG	Median
Refrigerant	R-410A	R-410A	R-410A	R-410A	N/A
Price (KRW)	NA	NA	691.000	650.000	605,000*
Price (US-$)*	NA	NA	620	580	540**

These products are registered within the energy efficiency label scheme (2013-2015)
* 1 US-$ = 1176.471 KRW (Dec 2015)
** Based on prices available for 117 products below 5.2 kW cooling capacity.

Table 19: Selected energy-efficient single-split air conditioner with a cooling capacity between 5.2 kW to12 kW, available in South Korea

Specifications	Samsung	LG	Samsung	LG	Median
Model	AF18J9970WWK	FNQ180PC1W/ FUQ180CAU	AF18HVWD1DF	FNQ167PASW/ FUQ167PAU	
Inverter?	Yes	Yes	Yes	Yes	
Cooling capacity (kW)	7.2	7.2	7.2	6.5	7.1
Heating capacity (kW)	-	-	-	-	-
CSPF or EERa	9.60	9.35	9.05	9.01	6.01
Annual energy consumption (kWh/a)	243	250	258	234	379
Refrigerant	R-410A	R-410A	R-410A	R-410A	N/A
Price (KRW)	3,361,000	2,857,000	2,942,000	3,119,000	1,484,000*
Price (US-$)*	2.990	2.540	2.620	2.780	1.330**

These products are registered within the energy efficiency label scheme (2013-2015).
* 1 US-$ = 1176.471 KRW
** Based on prices available for N=279 products above 5.2 kW up to 12 kW cooling capacity

5 Technology trends

5.1 Refrigerants

The most dominant refrigerant used in room AC in Asian countries is HCFC-22 (ozone depleting potential = 0.055, GWP = 1810[70]). Due to the commitments under the Montreal Protocol[71], HCFC Phase-Out Management Plans (HPMPs) have been established which define the phase-out schedule of ozone-depleting substances (ODS). Under these commitments, HCFCs have increasingly been replaced by HFCs, which do not have ozone depleting potential (ODP), but high global warming potential (GWP). At the moment a widely used alternative refrigerant to HCFC-22 is HFC-410A with a GWP of 2088. In addition to the high GWP value, HFC-410A has been criticised for reducing the system performance at high ambient temperatures (Rajadhyaska et al. 2014).

Due to the current climate debate, the envisaged phase-down of HFCs in the European Union (Regulation (EU) No. 517/2014[72]) and the recently agreed global phase-out of HFC (Kigali HFC amendment to the Montreal Protocol) there are increased considerations and efforts to replace high GWP HFC by low-GWP refrigerants. For single-split AC different tendencies are observed: European countries focus on natural refrigerants (e.g. hydrocarbons) with a GWP lower than 5, some Asian countries focus on the alternative refrigerant R-32 (GWP 675). However, there are also Asian countries such as China that have an increased interest in hydrocarbon technology. To promote the R-32 technology, the Japanese AC manufacturer Daikin allows free licences for selected patents „Basic Patent Indispensable for the Manufacture and Sale of Air Conditioners Using R-32 Single Component Refrigerant“ (since September 2011). Both hydrocarbons and R-32 are flammable refrigerants and need additional safety requirements. Due to the high GWP, the refrigerant R-32 seems unacceptable with regard to the current climate debate. Furthermore, pre-charged imported single-split air conditioners containing high-GWP HFC refrigerants will lead to a conflict with the requirements of Regulation No 517/2014 (see Chapter 7). This is important, considering the fact that Germany is an import market only (see Chapter 4.2).

Another recently introduced refrigerant group are unsaturated HFCs (marketed as "HFOs" or "Hydrofluoroolefins"), produced and promoted by the companies Honeywell, DuPont, Arkema and some Japanese producers. These substances have low GWP and when mixed, also with some conventional HFC, can be considered as 'drop-ins', i.e. there is no need to significantly modify the system design when refilled with certain unsaturated HFC/HFC blends.

However, existing studies on unsaturated HFCs (uHFCs) show negative environmental impacts. For example, it is known that the decomposition of uHFCs in the atmosphere leads to formation of trifluoroacetic acid (TFA). TFA is a strong acid with toxicity to some organisms (Key et al. 1997) and highly persistent with no known degradation mechanism (Ellis et al. 2001). TFA exists naturally in the oceans in very low concentrations, but not in fresh water or other terrestrial ecosystems (Christoph 2002). Whilst only 10-20% of commonly used HFC (e.g. HFC-134a) is transformed into TFA in the environment, 100% of the uHFC-1234yf (most common uHFCs) reacts to TFA. Above, the combustion of uHFCs (e.g. in case of fire or brazing work) can lead to the formation of hydrogen fluoride and carbonyl fluoride (uHFC 1234yf, Honeywell Material Safety Data Sheet (MSDS), 2014). HF is highly toxic and corrosive and can cause severe burns or blindness and lead to death when inhaled. Similar, carbonyl

70 All GWP values given according to: IPCC Fourth Assessment Report: Climate Change 2007 – Working Group I: The Physical Science Basis (Chapter 2.10.2 Direct Global Warming Potentials); https://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

71 http://ozone.unep.org/en/treaties.php

72 Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 (OJ L 150 of 20.05.2014, p. 195)

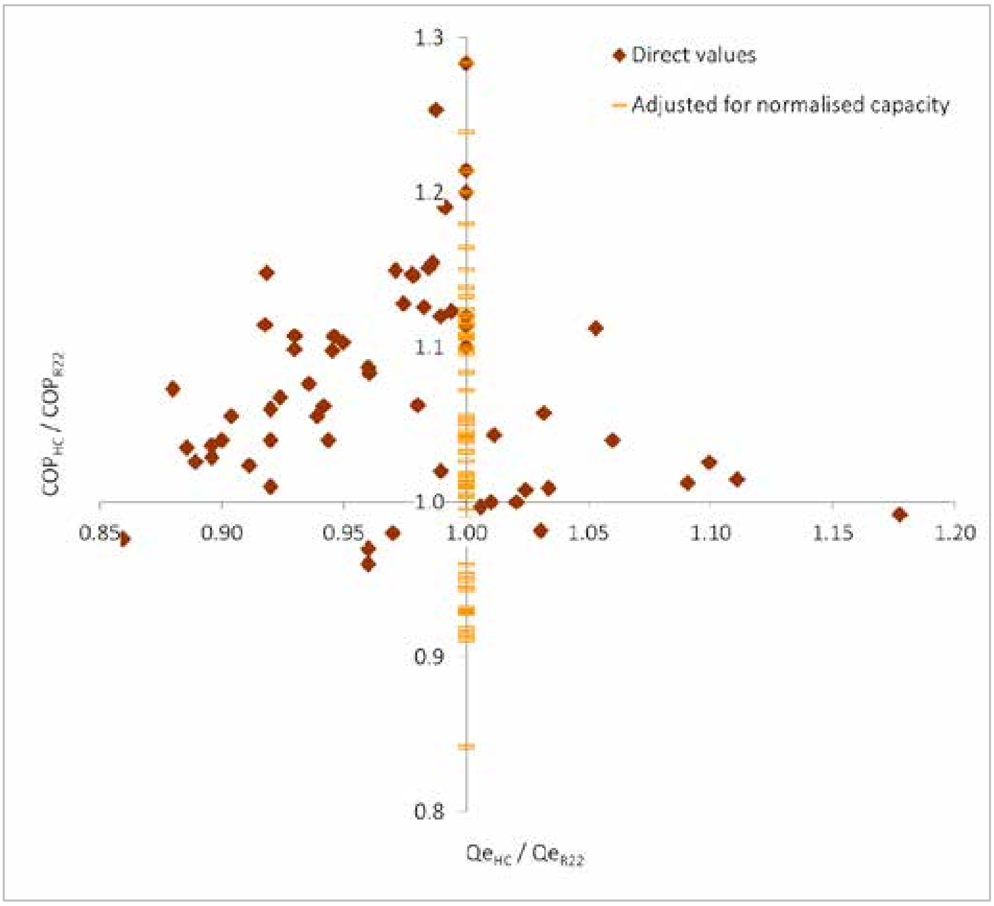
fluoride is a highly toxic substance with a NFPA rating for health of 4 on a scale from 0 to 4[73], which can lead to mortality of humans exposed to sufficiently high concentrations. Further disadvantages of these patented products, particularly for use in developing countries, are the high costs of unsaturated HFCs.

Historical evidence has demonstrated the severe negative environmental consequences of unconsidered actions, e.g. replacing ODS by HFC in the refrigeration and air conditioning sectors. Indeed, this replacement was a remarkable concerted action under the Montreal Protocol to safeguard the ozone layer, however, ODS have largely been replaced by HFC, potent GHG which contribute to global climate change. After the dimension of the environmental impacts have been realized, many countries started leapfrogging and directly considered natural refrigerants.

An environmental friendly and sustainable option is given with hydrocarbon (HC) refrigerants (natural refrigerants). HCs are particularly suitable for small appliances such as room air conditioners; the use of HCs is considered as state-of-the-art in many other refrigeration appliances such as domestic refrigerators (isobutane, R-600a) and stand-alone commercial units (propane, R-290). Apart from the mentioned advantages, HC-systems often show higher energy efficiency (Godrej 2013, Haier 2013) due to their thermo-physical properties. They also remain highly efficient in hot climates (Rajadhyasha et al. 2014). The data in Figure 17 summarises the test results from various published studies, which compared R-290 or R-1270 against R-22 in room air conditioners. Brown data points show the ratio of capacity with R-290 to R-22 (x-axis) against ratio in COP with R-290 to R-22 (y-axis). Yellow datapoints show the same results but with the COP ratio adjusted for a normalised cooling capacity. Since R-290 has a smaller volumetric refrigerating capacity than R-22, this can result in a smaller cooling capacity, but increasing the R-290 cooling capacity by means of larger displacement by faster compressor speed can imply poorer efficiency due to subsequent increased pressure losses. The COP data is therefore adjusted downwards to account for this. Overall, it can be seen that about 90% of the tests give higher COP for HCs.

[73] NFPA 704: Standard System for the Identification of the Hazards of Materials for Emergency Response. Rating 4 in the health section: "Very short exposure could cause death or major residual injury"

Figure 17: Energy efficiency improvements by using hydrocarbon refrigerants instead of HCFC-22, which is still commonly used in developing countries



The x-axis shows the ratio of cooling capacities with R-290 to HCFC-22 based air conditioners, the y-axis shows the ratio in COP with R-290 to HCFC-22 based air conditioners. Each dot (brown point) represents one comparative study. The majority of R-290 systems have a superior COP (> 1 on the y-axis) than HCFC-22 based air conditioners, irrespective of the cooling capacity (x-axis). The results are robust against adjustments for normalised capacities (orange lines, see text for further explanations).
Source: Own illustration (HEAT)

The key message from Figure 17: AC systems using R-290 (propane) as refrigerants show higher energy efficiency as compared to AC systems using HCFC-22.

Prominent Chinese single-split AC manufacturers such as Gree[74], Midea and Haier plan to introduce HC-based single-split AC with the support of the MLF (Multilateral Fund) of the Montreal protocol. The Indian manufacturer Godrej & Boyce, with the support of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and HEAT GmbH, already started with the production and sale of their energy efficient and environmentally friendly HC systems (R-290, propane) in 2012. So far more than 100.000 units have been sold in India. Similar the AC giant Gree has already converted a production line with the same support. Some 15–20 production lines of other manufacturers in China have also been converted for R-290 production under the HPMP.

A last critical aspect should be considered when using fluorinated refrigerants: these substances are produced from hydrofluoric acid (HF), which is again produced from fluorspar. Fluorspar is a depleta-

[74] Information of a GREE employee, who is majorly involved in the development of the R290-technology (Sep, 2014).

ble resource; the EU has included fluorspar in its list of the 14 most critical raw materials, defined by supply risk and economic importance (EC Enterprise and Industry, 2010). It is expected that fluorspar will be available for another 35 years if consumption stays constant and no other sources are discovered.

Key findings:

- Air conditioning systems using R-290 (propane) as refrigerant show higher energy efficiency as compared to air conditioning systems using HCFC-22 as refrigerant.
- An Indian manufacturer has already successfully introduced hydrocarbon-based single-split air conditioners on the market, various Chinese manufactures are currently converting their production lines to produce these kind of systems.
- Environmental and health risks are expected when using halogenated refrigerants

5.2 Energy Efficiency

5.2.1 Energy efficiency parameters EER and SEER

The energy efficiency of air conditioners is quantified with the index EER in many countries. ISO 5151 is the harmonized standard of testing method for air conditioners in this respect. However, this index does not account for the part load and seasonal energy efficiencies of air conditioners. Depending on the climate, part load represents a significant part of the operational mode, particularly in temperate climate zones.

A disadvantage of using the EER is that AC equipment was optimized by manufacturers in the past with regard to the specific testing conditions as defined under ISO 5151. However, under real climate conditions, which deviate from the defined testing conditions, AC equipment often performed poorly. Thus, seasonal energy efficiency parameters have been introduced in Europe and the U.S. and some Asian countries (Cooling Seasonal Performance Factor, CSPF) to account for a range of different outdoor temperatures. AC equipment with the part load operational mode often use inverter technology. To calculate seasonal energy efficiency parameters, such as CSPF, other standards than ISO 5151 must be considered, e.g. ISO 16358.

Comparing the energy performance of single-split system in different countries, such as Germany and India, is hampered by the applications of different energy performance parameters. While Germany is using SEER (seasonal energy efficiency ratio) values, the common parameter in India is EER. SEER values are generally 33% higher than EER values in temperate climate zones[75], but this rough rule might not be applicable when comparing countries with differing climates.

5.2.2 Inverter technology

Inverter technology is the most common technique to achieve variable speed drive of the compressor. It is increasingly used in single-split AC to improve the energy performance. This technology allows the AC system to operate close to its peak efficiency for the operating conditions irrespective of the cooling (or heating) demand, instead of the conventionally used fixed-speed compressors with on/off functionality. Inverter technology thus allows part-load operation, continuously regulating the compressor speed and therewith energy consumption to match the required cooling or heating demand. As part-load operation represents the majority of the operational mode of single-split AC units, particularly in countries with temperate climates, significant energy savings can be achieved.

75 Neue Ökodesign -Richtlinie 206/2012 für Raumklimageräte, Fachverband Gebäude-Klima e.V. (2012)

Higher efficiency is achieved, because of the improved pressure ratio (i.e. lower necessary pressure level) and temperature lift: the heat exchangers of the single-split AC system designed for full load are actually oversized when used for part-load conditions. A positive effect is that the temperature difference (refrigerant vs. air inlet temperature), which is necessary for the condensation and boiling process can be reduced. Consequently the compressor needs less power and therewith energy, furthermore a higher volumetric refrigerating effect is maintained, thereby providing higher efficiency. Another positive effect is given by reduced energy losses for on/off cycling (so-called cycling losses), except for very low part load ratios.

On the other hand, the reduced compressor speed can result in a decrease of the compressors isentropic efficiency as well as the efficiency of the inverter itself. These effects can slightly reduce the efficiency gains from the pressure ratio and refrigerant effect, as described above. The overall efficiency gains are particular high for large AC units. According to SEAD (2013), inverter technology achieves energy savings in the magnitude of 20-25% compared to conventional AC technology with fixed-speed compressors (on/off cycling).

On a global scale, the penetration rate (percentage of sold units) of inverter units in the AC market is estimated to be 30% (year 2012). This technology is commonly found in Japan, the EU, the US and some Asian countries such as China. In Japan and Oceania the penetration rate is estimated at 100%, in China and the EU with 50% and less than 20% in the rest of the world[76]

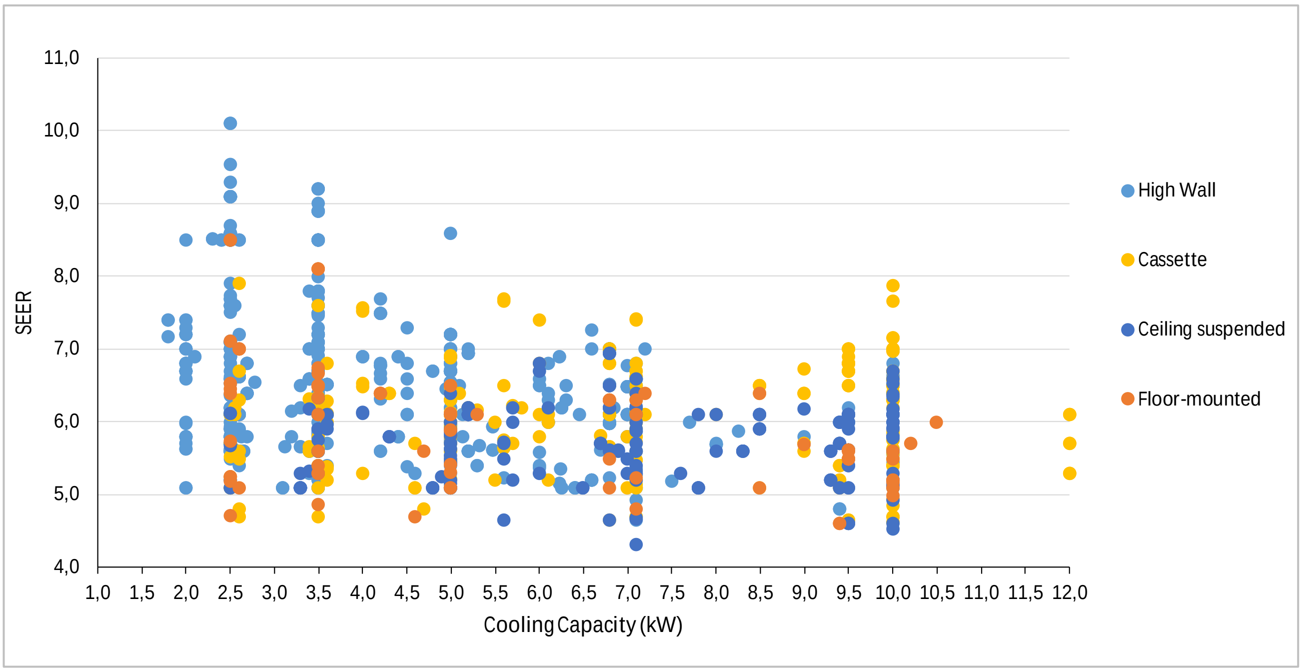
Also the increasing use of seasonal energy performance metrics (SEER, APF for Japan) for energy labels and MEPS support the growing trend of inverter controlled ACs.

Other features which improve the efficiency of air conditioners are electronic expansion valves (EEV), advanced heat exchanger design and variable speed fan motors.

Figure 18 provides an overview of the spectrum of SEER values of wall-mounted single-split air conditioner found in the European Union, with cooling capacities ranging from 1 to 12 kW. These data were considered to define the SEER value of the reference system within the LCA (Chapter 6).

[76] http://www.ejarn.com/news.asp?id=25298&classid=10

Figure 18: SEER values of wall-mounted single-split air conditioner in the European Union



Source: Own illustration (HEAT), based on Eurovent data[77]

Heat exchanger, charge size and safety standards

An improvement of the energy efficiency is also realised by increasing the heat exchanger, which translates into higher charge sizes. However, this is critical when using flammable refrigerants (such as R-290), and will conflict with the common safety standards at a certain point, e.g. DIN EN 60335-2-40.

The highest European efficiency class is currently difficult to realise under this standard, which limits the maximum charge of flammable refrigerants (see also Annex II). This holds true for temperate climates with a heat load of 100 W/m². In a tropical climate with 200 W/m² (i.e., "bigger" air conditioner with higher cooling capacity), A+++ is incompatible with the current version of product standard EN 60335-2-40. Please see also Annex II for further elaboration on this issue.

5.2.3 Auto-cleaning technologies and the effects on energy efficiency

During operation, dust accumulates on the filters of the indoor unit. Clogged filters hamper normal airflow which may lead to lower cooling performance and higher energy consumption. Thus auto-cleaning functionalities of air conditioners can have a strong impact on the energy efficiency. Empirical studies have shown that reductions in energy consumption of about 30-50% are possible, depending on the circumstances[78].

In addition, dust may bypass the filters due the decreased air flow, and dust-carrying air may be blown directly onto the evaporator coil / the coil's fins and reducing the coil's capability to absorb heat after

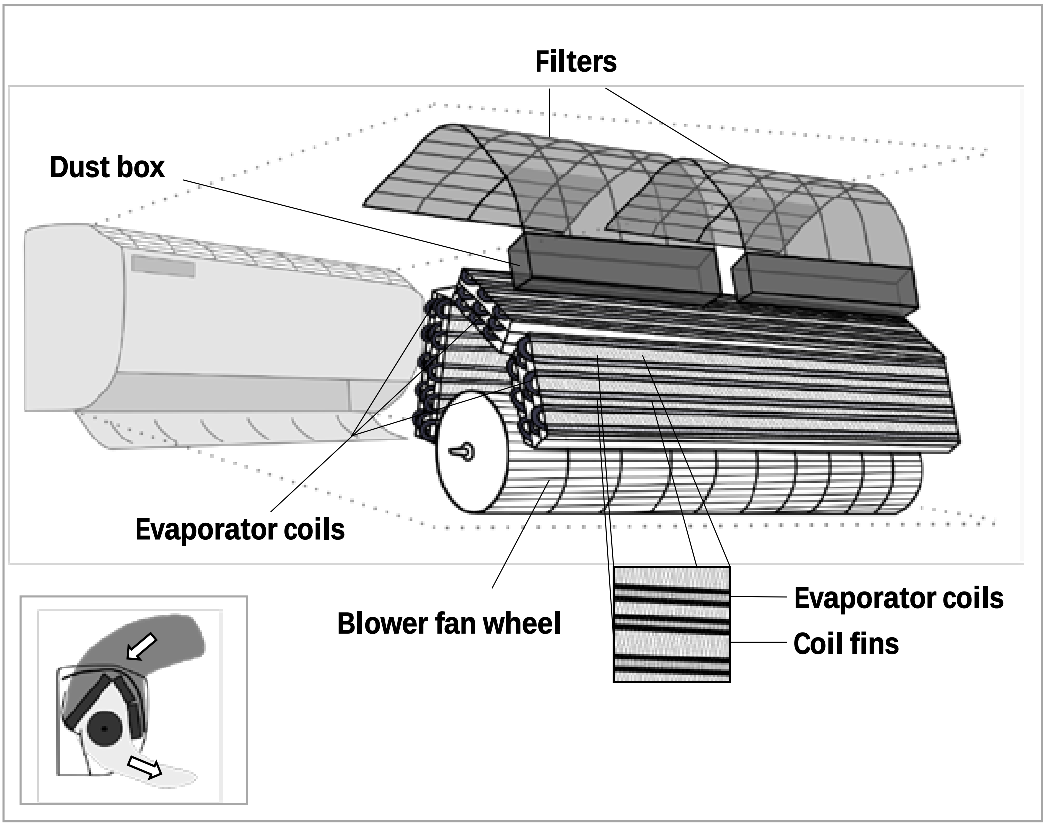
[77] http://www.eurovent-certification.com/

[78] Daikin auto-cleaning cassette system: http://tclairconditioning.co.uk/air-conditioning-equipment/daikin-self-cleaning-air-conditioning-provide-proven-energy-savings/

settling. The same holds true for the outdoor unit. Dust accumulation on the filters also provides substrate for germs, negatively affecting air quality in the room and possibly human health.

Auto-cleaning features, i.e. without manual controlling, are available in split systems (Figure 19).

Figure 19: Self-cleaning technologies of split air conditioners, exemplary shown for a wall-type unit



Source: Own illustration (HEAT)

Technical solutions to remove pollution rely on the same principle. Mechanical auto-cleaning of filters from dirt and dust is commonly realised by a brush which removes particles off the filter in the process of skimming over its surface. The remains are deposited inside a dust box. Two types are found, either the brush moves across the filter surface (upwards or sideways) or the brush is fixed and the filter is moving (e.g., Daikin's *Ururu Sarara*). Additionally hydrophilic and bactericidal materials such as aluminium foils coating the evaporator coils allow the rinsing of dirt particles from the heat exchanger (fins) by condensate water which is produced during refrigeration or dehumidification. The drainage and dehumidification reduces the risk of mould.

Depending on the product, different filters are employed for cleaning air. Filter technologies are generally capable of:

- filtering of larger-sized particles, dust and fine-particulate matter (PM 2.5);
- neutralisation of allergens, mould, bacteria, viruses, and odour;
- disinfection of room air but also interior of the indoor unit via release of ions into the room which neutralize small biological particles.

The filters might also be cleaned manually: this can be done by opening the panelling, removing the filters by hand without any tools. Afterwards the filters are water-cleaned without using additives.

6 Ecological and economic impact analysis

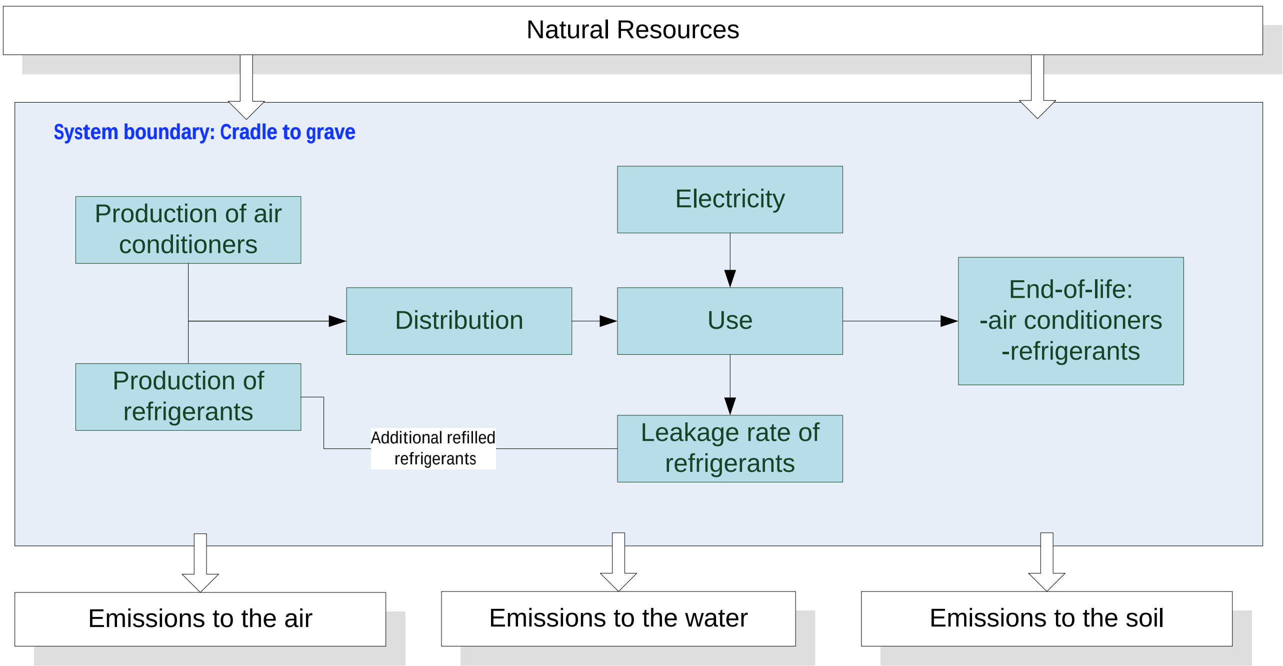
6.1 Streamlined life cycle assessment (LCA)

6.1.1 Goal and definition of scope

The following streamlined life cycle assessment (LCA) analysis aims at the identification of the contributions to the overall environmental impacts of air conditioners with a focus on the entire lifetime. For this, two products with different refrigerants according to different GWP values are chosen. Furthermore, single-split systems with a cooling capacity smaller than 5 kW objects are investigated, since they are the most dominant product group in residential buildings.

For the LCA, it is assumed that both products are manufactured in China (compare market analysis in Chapter 4.3) and then transported to Germany. Accordingly, they are used and treated in Germany. The system boundary of the investigated products is characterized as illustrated below (Figure 20). The life cycle of air conditioners is roughly divided into 4 stages: (1) production including raw material acquisition, (2) distribution, (3) use and (4) end-of-life treatment (i.e. cradle-to-grave).

Figure 20: System boundary



Source: Own illustration (Oeko-Institut)

6.1.2 Function and functional unit

The function of air conditioners is defined as cooling and heating the room air in residential areas. Other additional functions such as (de-)humidification, cleaning etc. are not considered in the following. Hence, the functional unit is defined as one air conditioner used in Germany over the period of one year. The overall lifetime of the device is assumed to be 10 years. Furthermore, it is assumed that during this period no spare parts have to be replaced and that no repairs are necessary. The cooling hours and heating hours per year are described in Table 20.

Table 20: Reference Data for Heating and Cooling Hours per Year (h/a)

Parameters	Assumed value	Source
Time of use for cooling in Germany per year	350 h/a	Regulation (EU) No 626/2011
Time of use for heating in Germany per year	1400 h/a[79]	Regulation (EU) No 626/2011

6.1.3 Environmental impact categories

The following environmental impact categories are considered:

- Climate change, GWP 100a (kg CO_2e)
- Cumulative energy demand - non-renewable energy resources (MJ-e)
- Cumulative energy demand - renewable energy resources (MJ-e)
- Terrestrial acidification (kg SO_2e)
- Freshwater eutrophication (kg P-e)
- Photochemical oxidant formation (kg NMVOC)
- Ecotoxicity (CTU: Comparative Toxic Unit)
- Human toxicity (CTU: Comparative Toxic Unit)

6.1.4 Modelling of air conditioners including refrigerants

6.1.4.1 Production of air conditioners and refrigerants

Production of air conditioners

As a first step of the modelling, two reference products are chosen. They differ according to the following refrigerants used:

- Product A with R-410a,
- Product B with R-290 (Propane).

The components and materials used for the two products are illustrated in the Table 22. The total weight of product A is calculated as an average value based on 20 air conditioners with a cooling capacity smaller than 2.5 kW (various product sheets). The weight of product B is more sophisticated to obtain, since air conditioners with R290 have not emerged in the German market yet. Hence, the total weight of product B is extrapolated based on the mass balance of the compressors, condensers and evaporators between product A and product B (Table 22). Finally, it is assumed that all other components of the two products are equal.

The dominant component of the outdoor unit is the compressor. The weight of the compressors of the two reference products was identified according to data by HEAT GmbH. The weight of other components with the same materials is determined on the basis of the mass percentages from the EuP Study (Rivière 2008). Regarding the electronic components the mass percentage of capacitors accounts for 0.4% of total weight of the device, which is based on De Kleine (2009).

[79] The heating hours are given by the calculation procedure as formulated in the Regulation (EU) No 626/2011. However, the 'real' heating hours in Germany might be lower.

Table 21: List of components and materials of product A and product B

	Product A: R-410A [kg/Unit]	Product B: R-290 [kg/Unit]	Source
Compressor	6.70	13.80	HEAT 2015
Steel-components	12.48	7.23	Calculated based on EuP Study
Aluminium-components	3.3	3.34	Calculated based on EuP Study
Copper-components	6.07	6.79	Calculated based on EuP Study
Plastics-components: PP	7.04	7.75	Calculated based on EuP Study
Plastics-components: PA6	0.85	0.94	Calculated based on EuP Study
Electronic-components:	1.34	1.48	Calculated based on EuP Study
· Printed circuit board (20%)	0.27	0.30	Assumption
· Capacitors (10%)	0.13	0.15	Calculated based on De Kleine (2009)
· Copper wiring (70%)	0.94	1.03	Assumption
Other materials: Rubber	4.68	5.11	Calculated based on EuP Study
Total weight of devices	**42.2**	**46.5**	**HEAT (2015) and calculated**

Table 22: Weight of the evaporator, compressor and condenser

Components	Product A: R-410A [kg]	Product B: R-290 [kg]
Evaporator (indoor unit)	2.10	2.30
Compressor (outdoor unit)	6.70	13.80
Condenser (outdoor unit)	5.20	3.20

Source: HEAT (2015)

The upstream processes (i.e. raw material extraction and components manufacturing as well as their transportation) and downstream processes (general treatment of used devices and processed metals into secondary metals) are modelled according to ecoinvent datasets 3.1.

The input data on energy and water consumption in the production phase is based on the latest EuP Study (Rivière 2008) and is extrapolated on the basis of the weight of the products investigated. The electricity grid mix of China is modelled as a proxy, which is based on the assumption that devices are mainly manufactured in China. Diesel as the second energy source is assumed due to lack of information, since only total primary energy consumption and electricity consumption are documented in the EuP study.

Table 23: Energy and water consumption in the production phase

Inputs in the production phase	Product A: R-410A	Product B: R-290	Unit
Electricity	35.7	40.1	kWh/Unit
Diesel	45.3	51.0	MJ/Unit
Water	4.6	5.2	Litre/Unit

Calculation based on the EuP study, Rivière (2008)

Production and distribution of refrigerants

Two types of refrigerants are investigated in this study: R-290 and R-410A. R-290 is propane. R-410A is a mixture of difluoromethane (CH_2F_2, termed R-32) and pentafluoroethane (CHF_2CF_3, termed R-125), The datasets in the Ecoinvent 3.1 are used for the modelling of the production phase.

Productions of trifluoromethane and hexafluoroethane are used for the modelling of the production of difluoromethane (R-32) and pentafluoroethane (R-125) as a proxy due to a lack of data (Table 24). The distribution of the refrigerants is already considered in the used ecoinvent datasets.

Table 24: Datasets used for modelling the production and distribution of the refrigerants

Refrigerants	Chemical formula	Datasets in ecoinvent 3.1
R-290 (Propane)	C_3H_8	Market for propane [GLO]
R-410A	CH_2F_2 (50%)+CHF_2CF_3 (50%)	Market for hexafluoroethane [GLO]; market for trifluoromethane [GLO]

Distribution of air conditioners

It is assumed that the final products are transported from China to Germany by both, sea and land transportation. Freight transport is weighted according to the delivery weight. This means that environmental impact results associated with the distribution of the two investigated products are slightly different due to their weight difference. Further assumptions for the modelling of the distribution are described in Table 25.

Table 25: Assumptions for the modelling of the distribution

Mode of transport	Km
Sea, transoceanic ship	10,000
Road, lorry	1,000

The distribution of refrigerants is already considered within the production phase, since datasets in ecoinvent are used. For the purpose of simplification, the results are not depicted separately, because the distribution of refrigerants only has a marginal impact on the overall results.

Use phase

The cooling energy consumption of air conditioners depends very much upon the cooling capacity and the Seasonal Energy Efficiency Ratio (SEER) value of the devices as well as upon the time of use. As for heating energy consumption, heating capacity and the Seasonal Coefficient of Performance (SCOP) value and time of use play an important role. The total energy consumption including cooling and heating accounts for 1307 kWh per year of product A and 1140 kWh per year of product B (see Table 26). About 85% of both are due to heating. A detailed description of parameters used for the energy calculation is listed in Table 27 and Table 28.

Table 26: Energy consumption (cooling and heating) in the use phase of product A and product B

Energy consumption (kWh/a)	Product A: R-410A		Product B: R-290	
Annual energy consumption (cooling)	198	15.1%	175	15.4%
Annual energy consumption (heating)	1110	84.9%	965	84.6%
Total	1308	100.0%	1140	100.0%

Table 27: Parameters for the modelling of energy consumption (cooling and heating) in the use phase of product A

Product A: R-410A	Value	Unit
Cooling capacity	3.5	kW
Energy efficiency class (cooling)	between A++ and A+++	-
SEER (cooling)	6.2	W/W
Time of use for cooling in Germany	350	h/a
Annual energy consumption (cooling)	198	kWh/a
Heating capacity	3.17	kW
Energy efficiency class (cooling)	A++	
SCOP (heating)	4	W/W
Time of use for heating in Germany	1400	h/a
Annual Energy consumption (heating)	1110	kWh/a

Table 28: Parameters for the modelling of energy consumption (cooling and heating) in the use phase of product B

Product B: R-290	Value	Unit
Cooling capacity	3.5	kW
Energy efficiency class (cooling)	between A++ and A+++	-
SEER (cooling)	7	W/W
Time of use for cooling in Germany	350	h/a
Annual energy consumption (cooling)	175	kWh/a
Heating capacity	3.17	kW
Energy efficiency class (cooling)	A++	
SCOP (heating)	4.6	W/W
Time of use for heating in Germany	1400	h/a
Annual energy consumption (heating)	965	kWh/a

The leakage of refrigerants is assumed to be 5% per year in Germany (UBA 2014). Therefore, it is assumed that 37.5% of the initial amount is additionally refilled within the ten years of lifetime of an air conditioner. A total description of the life cycle of refrigerants is depicted in Figure 22.

Table 29: Initial charge of refrigerants and leakage rate in the use phase

Refrigerants	Product A: R-410A	Product B: R-290	Source
Initial requirement of refrigerants (kg)	1.10	0.55	Various product sheets, HEAT GmbH
Leakage rate (% per year)	5%	5%	UBA, FKZ 3711 43 324

6.1.4.2 End-of-life

End-of-life (EoL) of air conditioners

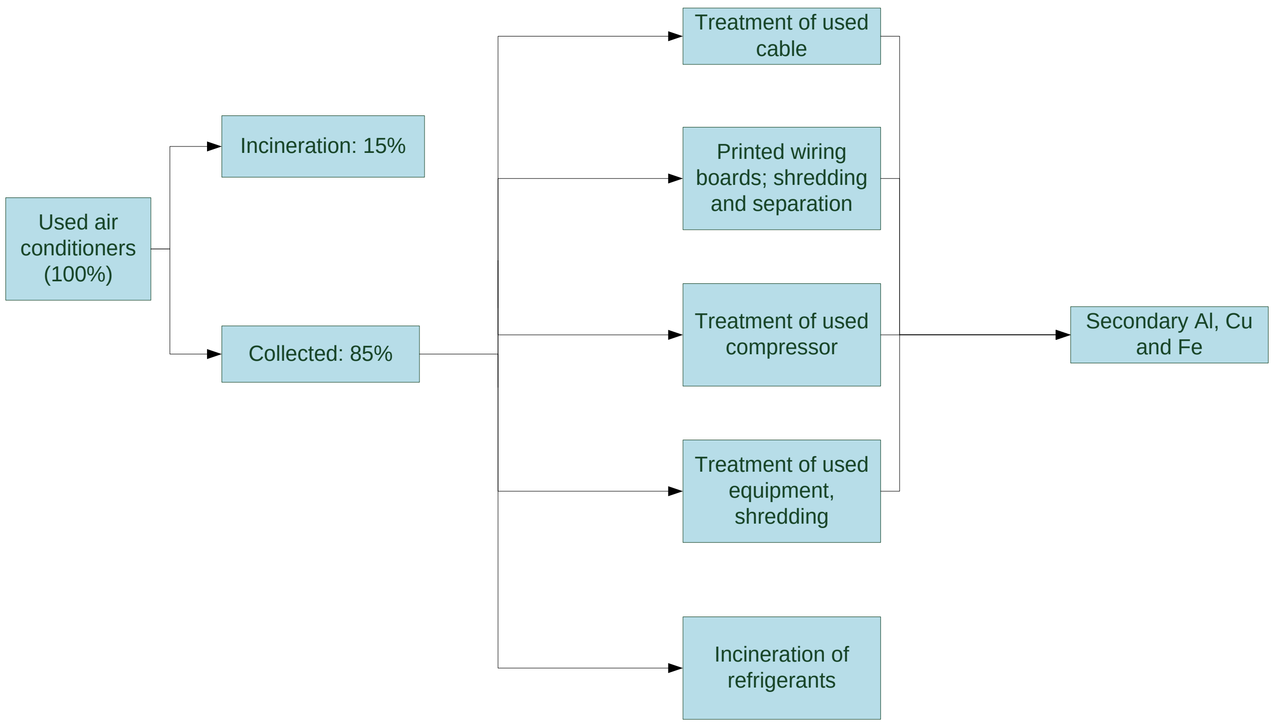
According to the EU WEEE Directive[80] (Waste Electrical and Electronic Equipment Directive, 2012/19/EU), air conditioners are classified as large household appliances. Compressors from air conditions should be treated separately, since they may disturb the shredding and mechanical separation process (Deubzer 2011). The refrigerants shall be removed.

According to EUROSTAT (EUROSTAT 2015), the recycling and reuse rate of large household appliances in Germany is 85%. Therefore, the following assumptions are made for the modelling of EoL of air conditioners:

- 85% of the air conditioners are collected and metals such as aluminium, steel and copper are further processed to secondary metals. The remaining fraction with 15% is assumed to be treated in incineration facilities.
- Refrigerants are incinerated as hazardous wastes.
- Debit from production of secondary metals is considered.
- Transport of used devices from the point of installation to the disposal facility is not considered, since it only has a marginal impact on the overall results.

The following Figure 21 illustrates the modelling of end-of-life.

Figure 21: End-of-Life modelling of air conditioners



Source: Own illustration (Oeko-Institut)

80 Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE), (OJ 197 of 24.7.2012, p. 38)

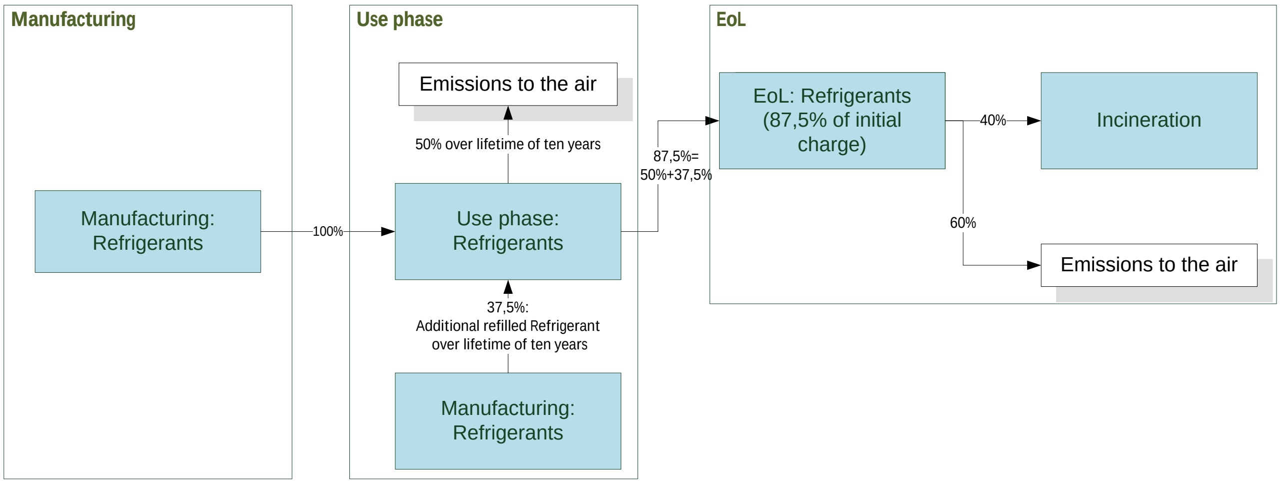
End-of-life of refrigerants

The mass flows of refrigerants regarding their total life cycle are described in Table 30.

Table 30: Mass flow regarding the total life cycle of refrigerants

Refrigerants	R-410A	R-290
	(kg/10a lifetime of air conditioner)	
Initial charge: refrigerants	1.10	0.55
Refilled refrigerants (=37.5% x initial amount)	0.413	0.206
Use Phase: leakage (=50% x initial amount)	0.550	0.275
EoL: leakage (=60% x 87.5% x initial amount)	0.578	0.289
EoL: incineration (=40% x 87.5% x initial amount)	0.385	0.193

Figure 22: The life-cycle of refrigerants



6.1.5 Results

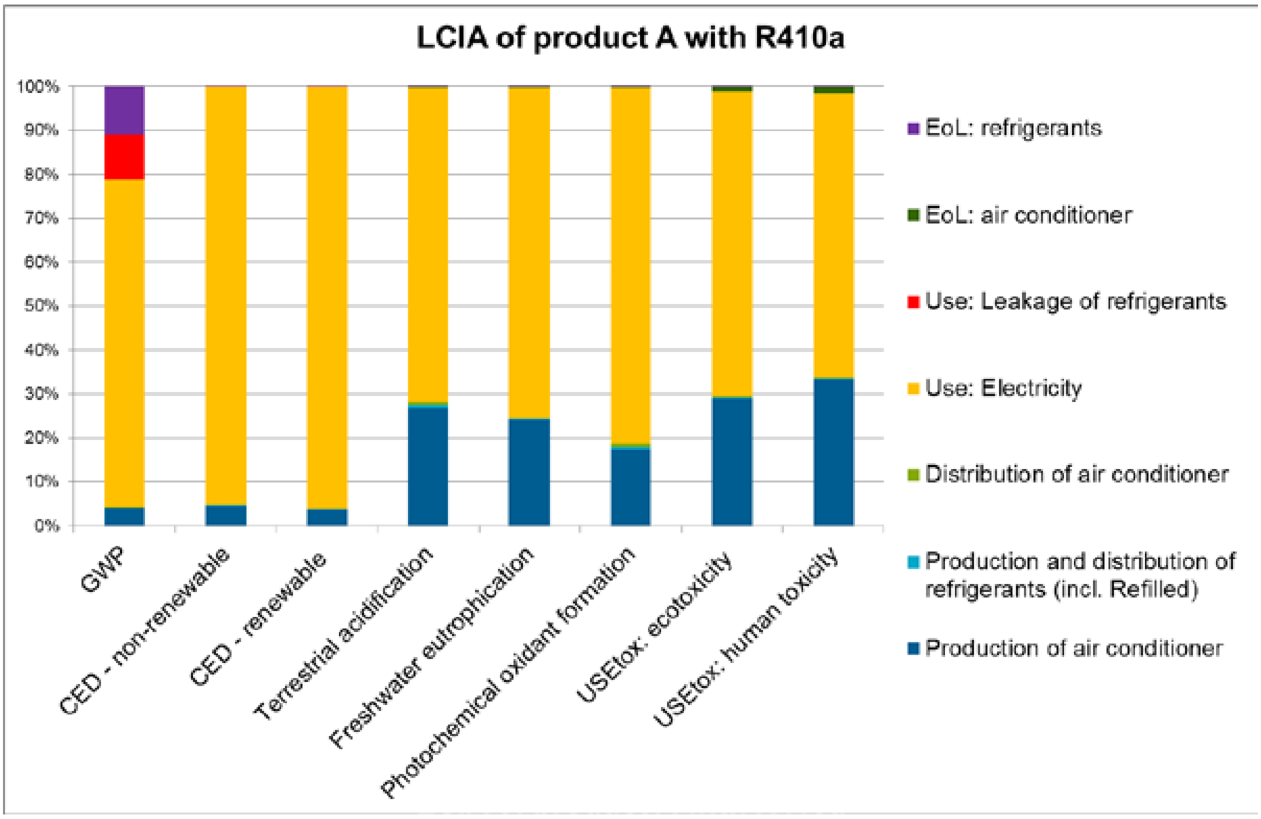
6.1.5.1 Results of the base case

In the following, Table 31 to Table 34 show the absolute results of the environmental impacts and the percentage shares of the individual life cycle phases of products A and B.

The results regarding product A with R-410A (see Figure 23) are:

- The production phase makes a relatively significant contribution (17%-33%) to certain environmental impacts (acidification, eutrophication, photochemical oxidant formation, ecotoxicity and human toxicity), while the use phase makes a very significant contribution to all environmental impacts, especially GWP and cumulative energy demand.
- The use phase accounts for the largest proportion of GWP emissions with 85% (electricity: 75%; leakage of R-410A: 10%), followed by the production phase of the air conditioner with 4%.
- The distribution of the air conditioners and the production of refrigerants only have a marginal environmental impact for all the investigated impacts.

Figure 23: Life-Cycle Impact Assessment (LCIA) results: Relative environmental impact per functional unit (per year) of the life cycle phases of product A with R-410A

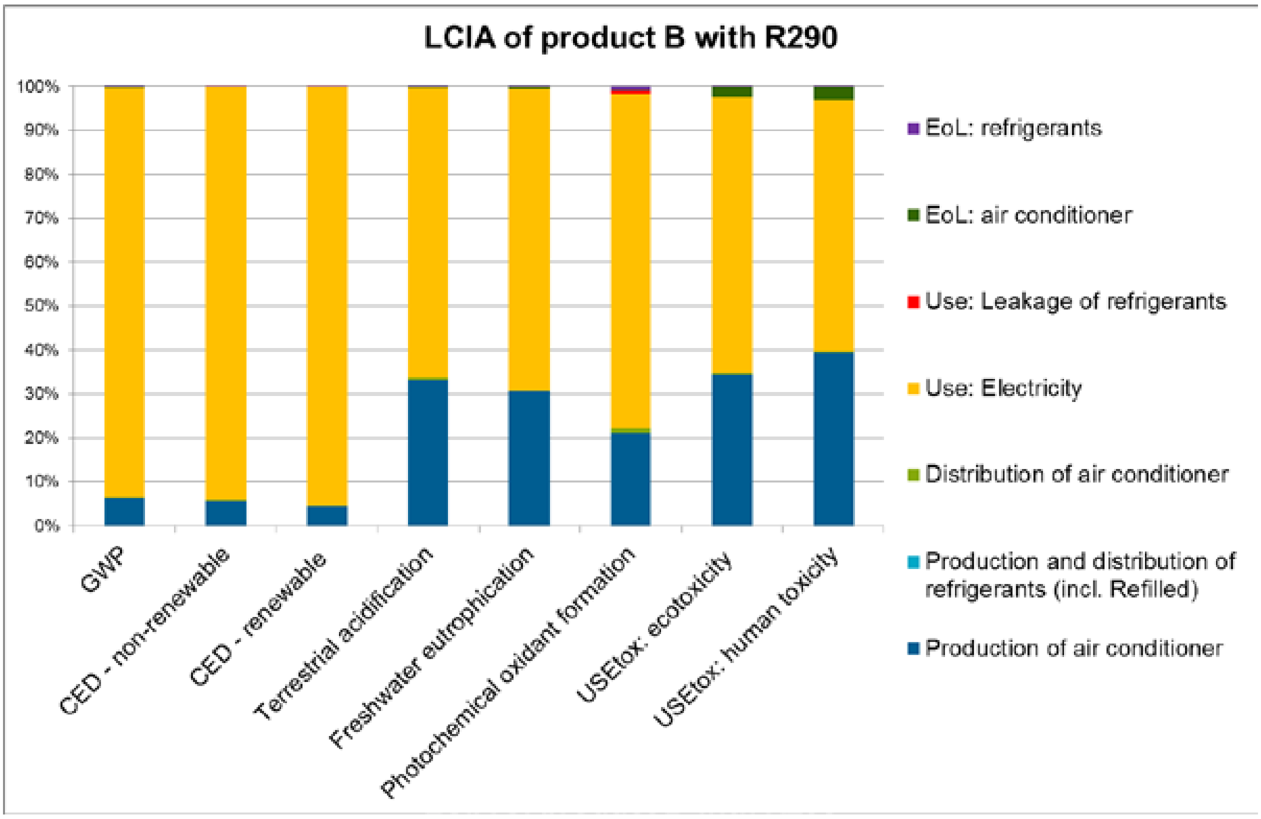


Source: Own illustration (Oeko-Institut)

The results regarding product B with R-290 (see Figure 24) are the following:

- The production phase makes a relatively significant contribution (21%-39%) to certain environmental impacts (acidification, eutrophication, photochemical oxidant formation, ecotoxicity and human toxicity), while the use phase makes a significant contribution to all environmental impacts, especially GWP and cumulative energy demand.
- The use phase accounts for the largest proportion of GWP emissions with 93%, followed by the production phase with 6%. The GWP emissions from the use phase are almost fully due to electricity consumption, since GWP of R290 is equal to 3.3 kg CO_2e/kg R-290 (compared to 2088 kg CO_2e/kg R-410A).
- Distribution of air conditioners and the production of refrigerants only have a marginal environmental impact of all investigated impacts.

Figure 24: Life-Cycle Impact Assessment (LCIA) results: Relative environmental impacts per functional unit (per year) of the life cycle phases of product B with R-290



Source: Own illustration (Oeko-Institut)

Table 31: Absolute environmental impact values per functional unit (per year) per life cycle phase of product A with R-410A

LCIA results of product A with R-410A	Unit	Production of air conditioner	Production & distribution of refrigerants (incl. refilled)	Distribution of air conditioner	Use: Electricity	Use: Leakage of refrigerants	EoL: air conditioner	EoL: refrigerants	Total
Climate change, GWP 100a	kg CO_2e	4,54E+01	1,54E+00	1,19E+00	8,33E+02	1,15E+02	8,04E-01	1,21E+02	1,12E+03
Cumulative energy demand – non-renewable energy resources	MJ-e	6,05E+02	2,53E+01	1,87E+01	1,29E+04	0,00E+00	6,57E+00	4,48E-01	1,36E+04
Cumulative energy demand – renewable energy resources	MJ-e	7,09E+01	1,89E+00	3,14E-01	1,79E+03	0,00E+00	7,54E-01	3,31E-02	1,86E+03
Terrestrial acidification	kg SO_2e	4,78E-01	1,23E-02	1,16E-02	1,28E+00	0,00E+00	2,64E-03	2,04E-04	1,78E+00
Freshwater eutrophication	kg P-e	3,85E-02	1,54E-04	1,85E-05	1,21E-01	0,00E+00	2,65E-04	3,53E-06	1,59E-01
Photochemical oxidant formation	kg NMVOC	2,09E-01	5,55E-03	9,91E-03	9,73E-01	0,00E+00	1,75E-03	1,94E-04	1,20E+00
USEtox: ecotoxicity	CTU	7,88E+01	5,67E-01	1,04E+00	1,88E+02	0,00E+00	3,11E+00	1,42E-01	2,72E+02
USEtox: human toxicity	CTU	3,47E-05	3,48E-07	1,82E-07	6,73E-05	0,00E+00	1,49E-06	1,19E-08	1,04E-04

Table 32: Percentage proportions per functional unit per life cycle phase of product A with R-410A

Product A with R-410A	Production of air conditioner	Production & distribution of refrigerants (incl. refilled)	Distribution of air conditioner	Use: Electricity	Use: Leakage of refrigerants	EoL: Air conditioner	EoL: Refrigerants	Total (%)
Climate change, GWP 100a	4%	0%	0%	75%	10%	0%	11%	100%
Cumulative energy demand - non-renewable energy resources	4%	0%	0%	95%	0%	0%	0%	100%
Cumulative energy demand - renewable energy resources	4%	0%	0%	96%	0%	0%	0%	100%
Terrestrial acidification	27%	1%	1%	72%	0%	0%	0%	100%
Freshwater eutrophication	24%	0%	0%	76%	0%	0%	0%	100%
Photochemical oxidant formation	17%	0%	1%	81%	0%	0%	0%	100%
USEtox: ecotoxicity	29%	0%	0%	69%	0%	1%	0%	100%
USEtox: human toxicity	33%	0%	0%	65%	0%	1%	0%	100%

Table 33: Absolute environmental impact values per functional unit (per year) per life cycle phase of product B with R-290

LCIA results of product B with R290	Unit	Production of air conditioner	Production & distribution of refrigerants (incl. refilled)	Distribution of air conditioner	Use: Electricity	Use: Leakage of refrigerants	EoL: Air conditioner	EoL: Refrigerants	Total
Climate change, GWP 100a	kg CO_2e	4,96E+01	5,72E-02	1,34E+00	7,27E+02	9,08E-02	1,10E+00	1,48E-01	7,79E+02
Cumulative energy demand - non-renewable energy resources	MJ-e	6,67E+02	3,85E+00	2,10E+01	1,13E+04	0,00E+00	1,09E+01	2,24E-01	1,20E+04
Cumulative energy demand - renewable energy resources	MJ-e	7,34E+01	1,69E-02	3,53E-01	1,56E+03	0,00E+00	1,27E+00	1,66E-02	1,64E+03
Terrestrial acidification	kg SO_2e	5,58E-01	4,21E-04	1,30E-02	1,11E+00	0,00E+00	4,40E-03	1,02E-04	1,69E+00
Freshwater eutrophication	kg P-e	4,67E-02	1,00E-06	2,08E-05	1,05E-01	0,00E+00	5,42E-04	1,76E-06	1,52E-01

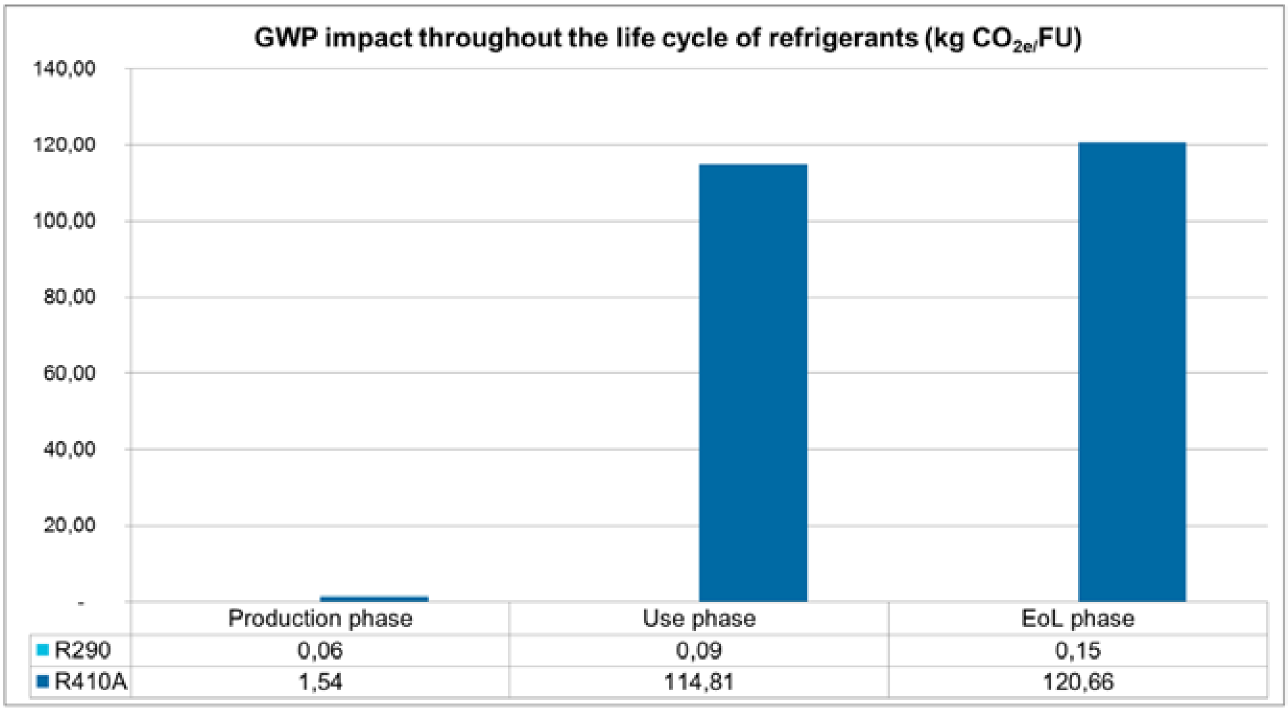
LCIA results of product B with R290	Unit	Production of air con-ditioner	Production & distribution of refrigerants (incl. refilled)	Distribution of air con-ditioner	Use: Electricity	Use: Leakage of refrigerants	EoL: Air condi-tioner	EoL: Refrigerants	Total
Photochemical oxidant formation	kg NMVOC	2,36E-01	2,90E-04	1,12E-02	8,49E-01	8,18E-03	2,91E-03	8,68E-03	1,12E+00
USEtox: ecotoxicity	CTU	8,96E+01	2,99E-02	1,17E+00	1,64E+02	0,00E+00	6,27E+00	7,08E-02	2,61E+02
USEtox: human toxicity	CTU	4,03E-05	4,22E-09	2,05E-07	5,87E-05	0,00E+00	2,99E-06	5,93E-09	1,02E-04

Table 34: Percentage proportions per functional unit per life cycle phase of product B with R-290

Product B with R290	Production of air conditioner	Production & dis-tribution of refrig-erants (incl. refilled)	Distribution of air condi-tioner	Use: Electricity	Use: Leakage of refrigerants	EoL: Air condition-er	EoL: Refrigerants	Total (%)
Climate change, GWP 100a	6%	0%	0%	93%	0%	0%	0%	100%
Cumulative energy demand - non-renewable energy resources	6%	0%	0%	94%	0%	0%	0%	100%
Cumulative energy demand - renewable energy resources	4%	0%	0%	95%	0%	0%	0%	100%
Terrestrial acidification	33%	0%	1%	66%	0%	0%	0%	100%
Freshwater eutrophication	31%	0%	0%	69%	0%	0%	0%	100%
Photochemical oxidant formation	21%	0%	1%	76%	1%	0%	1%	100%
USEtox: ecotoxicity	34%	0%	0%	63%	0%	2%	0%	100%
USEtox: human toxicity	39%	0%	0%	57%	0%	3%	0%	100%

The absolute environmental impact results of product A are similar to those of product B, with the exception of the environmental category GWP. This is due to the different refrigerants. Figure 25 compares the GWP values of R-410A and R-290 in the production and use phases (data referring to the functional unit). The values for R290 (light blue) are so marginal as compared to R410A (dark blue) that they do not even appear in the Figure.

Figure 25: GWP of refrigerants according to the life cycle phases



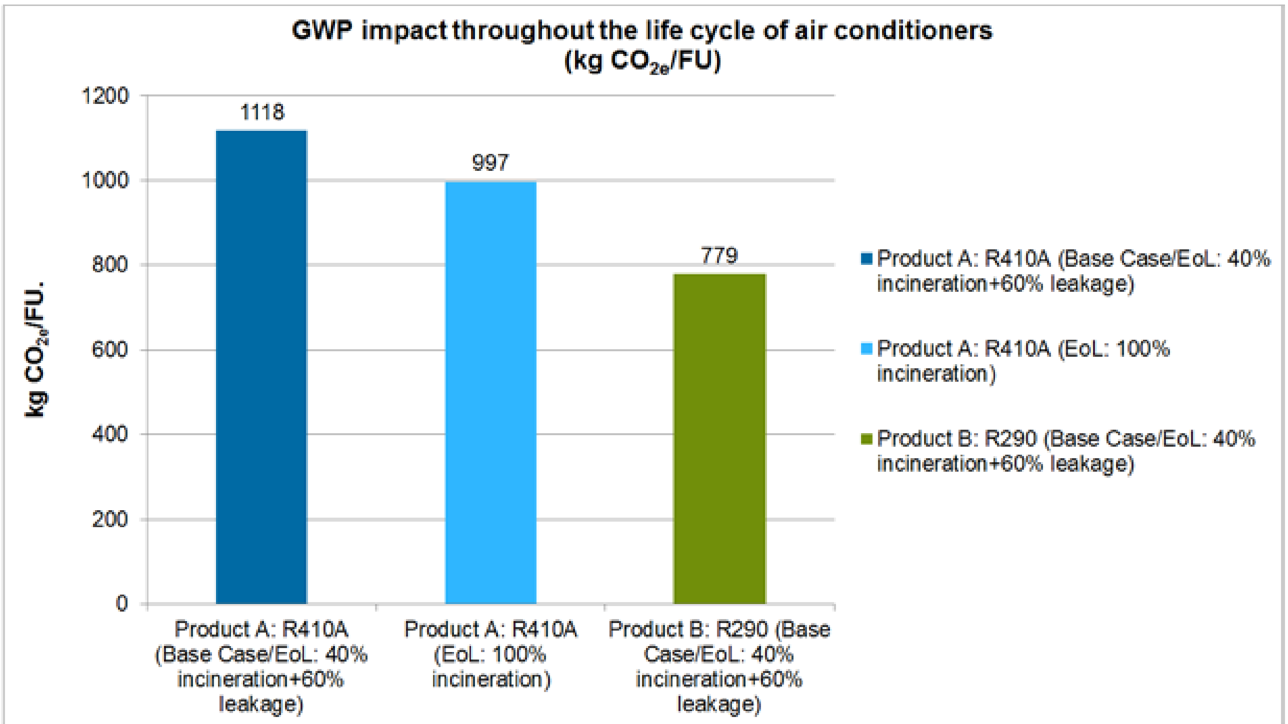
Source: Own illustration (Oeko-Institut)

6.1.5.2 Results of sensitivity analysis 1: Assumption of 100% incineration of R-410A in the EoL-phase

In the base case, 60% of the refrigerant is modelled as directly emitted to the atmosphere and the residual 40% go to incineration (see Figure 26). In this sensitivity analysis, it is assumed that after end of its life time the refrigerant R-410A is completely (100%) incinerated, to demonstrate the possible CO_2e saving potential as compared to the base case.

The results in Figure 26 show that in the sensitivity analysis, the total GWP-value of product A would be 11% lower than in the base case, in which 60% of R-410A are emitted into the atmosphere. Product B with R-290 still has the lowest direct emissions. Compared to Product A (100% incineration and base case), they are 22% and 30% lower, respectively.

Figure 26: Comparison between sensitivity analysis results of product A concerning EoL of R-410A and base case results of product A and product B



Source: Own illustration (Oeko-Institut)

6.1.5.3 Results of sensitivity analysis 2: Consideration of a tropical climate zone for the use phase

In the base case, it was assumed that the geographic coverage in the use phase is Germany. As this project also focusses on hot and humid climate zones, another sensitivity analysis is carried out taking this matter into account. In particular, it aims at an assessment of the influence of climate-related conditions and corresponding significant parameters and how they determine the LCA results. Hence, for this purpose, Thailand is chosen as a typical tropical country.

Therefore, no heating time is assumed as compared to the base case in Germany. The average time of use for cooling in Thailand assumed to be 2920 h/a. The lifespan for air conditioners in Thailand is assumed to be about 12 years, according to an inventory conducted in 2012 (Bright Management Consulting 2013). A comparison of the assumed parameters is illustrated in Table 35, where a differentiation between the base-case (Moderate Climate Zone/Germany) and this sensitivity analysis (Tropical Climate Zone/Thailand) is depicted.

Table 35: Comparison of assumed parameters between base case (Moderate Climate Zone/Germany) and sensitivity analysis 2 (Tropical Climate Zone/Thailand)

Geographic coverage in the use phase	Assumed parameters	Value
Germany (base case)	lifetime in years	10 years
	time of use for cooling	350 h/a
	time of use for heating	1400 h/a
Thailand (sensitivity analysis 2)	lifetime in years	12 years
	time of use for cooling	2920 h/a
	time of use for heating	0 h/a

The modelling of the other life-cycle phases such as production, distribution and end-of-life of the air conditioners remain unchanged. According to the different usage time in Thailand (compare parameters in Table 35), the amount of the electricity consumption and the corresponding background dataset for the Thai electricity mix are different.

In the Thai Scenario, the total energy consumption for cooling accounts for 1648 kWh per year for product A and 1460 kWh per year for product B (Table 36). A comparison of the respective energy consumption of product A and product B used in Germany and Thailand is summarized in Table 37 and Table 38. The results show that in Thailand – due to the different climate-related conditions – around 25% more energy is consumed as compared to the base case (Germany).

Table 36: Energy consumption (cooling) in the use phase of product A and product B in Thailand (sensitivity analysis 2)

Thailand	Unit	Product A: R410A	Product B: R290
Cooling capacity	kW	3,5	3,5
Energy efficiency class (cooling)		between A++ und A+++	between A++ und A+++
SEER (cooling)	W/W	6,2	7
Time of use for cooling in Thailand	h/a	2920	2920
Annual energy consumption (cooling)	**kWh/a**	**1648**	**1460**

Table 37: Comparison of annual energy consumption of product A used in Thailand with used in Germany (base case)

Energy consumption (kWh/a)	Product A: R410A	Product A: R410A
Geographic coverage in the use phase	Germany (base case)	Thailand (sensitivity analysis 2)
Annual energy consumption (cooling)	198	1648
Annual energy consumption (heating)	1110	0
Total (kWh/a)	1307	1648
Compared to base case	100%	126%

Table 38: Comparison of annual energy consumption of product B used in Thailand with used in Germany (base case)

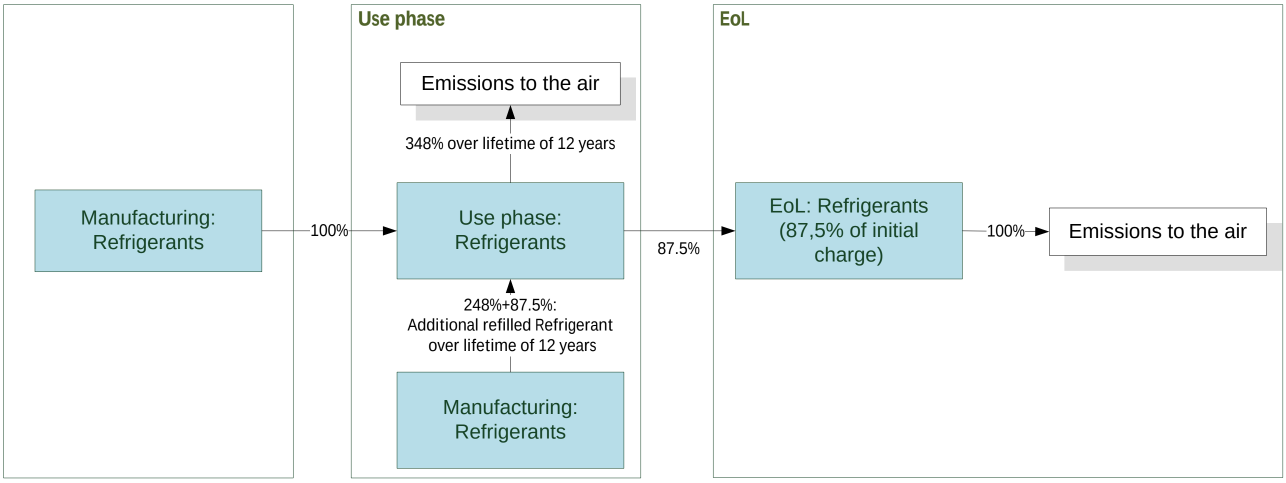
Energy consumption (kWh/a)	Product B: R290	Product B: R290
Geographic coverage in the use phase	Germany (base case)	Thailand (sensitivity analysis 2)
Annual energy consumption (cooling)	175	1460
Annual energy consumption (heating)	965	0
Total (kWh/a)	1140	1460
Compared to base case	100%	128%

The leakage rate in Thailand is assumed to be 29% per year (UNEP 2013). The mass flows of refrigerants regarding their total life cycle are described in Table 39 and depicted in Figure 27.

Table 39: Mass flow regarding the total life cycle of refrigerants (sensitivity analysis 2: Thailand)

Refrigerants	R410a (kg/12a lifetime of air conditioner)	R290 (kg/12a lifetime of air conditioner)
Initial charge: refrigerants	1.10	0.55
Use: Leakage rate (% per year) in Thailand	29%	29%
Use: Leakage rate (% over lifetime of 12 years) in Thailand	348%	348%
Use Phase: leakage (29% per year x initial amount x 12 a)	3.828	1.914
Refilled refrigerants (=(248%+87.5%) x initial amount)	3.691	1.845
EoL: leakage (=100% x 87.5% x initial amount)	0.963	0.481

Figure 27: The life-cycle of refrigerants (sensitivity analysis 2: Thailand)



Source: Own illustration (Oeko-Institut)

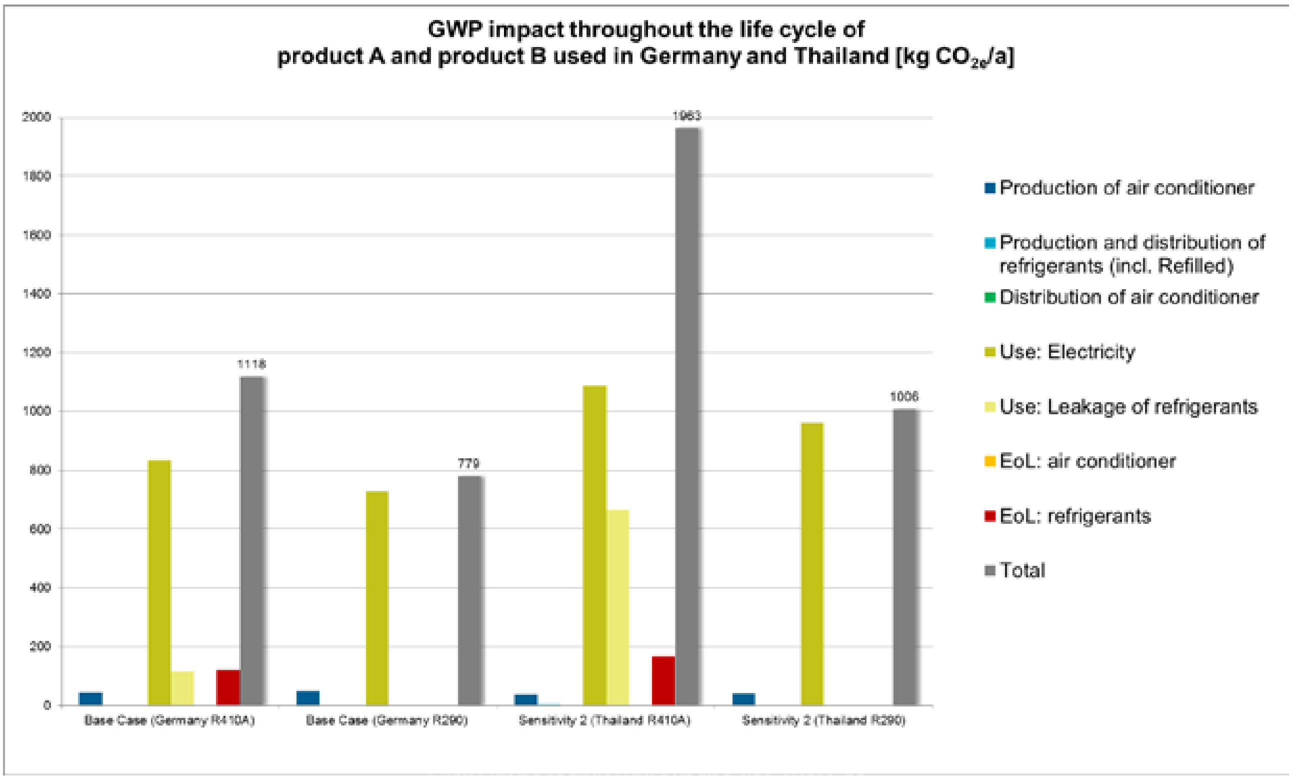
In this sensitivity analysis, only the GHG impact (GWP) is considered. The functional unit was defined as one air conditioner used in Germany over the period of one year in the base case. In order to make the results comparable, the life time of air conditioners is required (Table 35). The results therefore refer to the GHG emissions per year. The results of the GHG impact of product A and product B in this sensitivity analysis are presented together with the results of the base case in Table 40 and Figure 28.

Table 40: GHG impacts per functional unit (per year) of the life cycle phases of product A and product B used in Germany and in Thailand

GWP impact [kg CO_2e/a]	Product A with R410a		Product B with R290	
	Base case (Germany)	Sensitivity analysis 2 (Thailand)	Base case (Germany)	Sensitivity analysis 2 (Thailand)
Production of air conditioner	45.37	37.81	49.64	41.37
Production and distribution of refrigerants (incl. refilled)	1.54	4.06	0.06	0.15
Distribution of air conditioner	1.19	0.99	1.34	1.12
Use: Electricity	833.14	1086.29	726.50	962.14
Use: Leakage of refrigerants	114.81	665.91	0.09	0.53

GWP impact [kg CO_2e/a]	Product A with R410a		Product B with R290	
	Base case (Germany)	Sensitivity analysis 2 (Thailand)	Base case (Germany)	Sensitivity analysis 2 (Thailand)
EoL: air conditioner	0.80	0.67	1.10	0.92
EoL: refrigerants	120.66	167.43	0.15	0.13
Total	**1117.51**	**1963.16**	**778.89**	**1006.36**

Figure 28: GWP impact throughout the life cycle of product A and product B used in Germany and Thailand



Source: Own illustration (Oeko-Institut)

The results show that in the base case (Germany), product A (refrigerant R410A) has a total annual GHG impact of 1117.51 kg CO_2e/a as compared to 778.89 kg CO_2e/a of product B (refrigerant R290, propane). Hence, the GHG savings per year of product B compared to product A amount to about 30%.

In the sensitivity analysis 2, where the two products are compared under the assumptions of operating in a tropical climate zone (hot/humid), product A (refrigerant R410A) has a total annual GHG impact of 1963.16 kg CO_2e/a as compared to 1006.36 kg CO_2e/a for product B. Hence, the GHG savings per year of product B compared to product A amount to around 49%.

6.2 Life-cycle cost (LCC) analysis

Life cycle cost (LCC) analysis includes all consumer expenditures throughout the lifetime of products (in this case: similar to LCA, a lifetime of 10 years is assumed), which include:

- purchasing prices,
- installation costs,
- repair and maintenance costs
- operating costs due to electricity consumption
- uninstalling costs.

The underlying parameters for the calculation of the costs are presented in Table 41. As for the installation and uninstalling of the air conditions, 2 technicians are necessary, taking them 7-8 hours for installing and 2-3 hours for uninstalling.

Table 41: Parameters for the calculation of LCC

Cost Parameter	Unit	Value	Source
Sales prices	Euro/unit	900	UBA (2014), FKZ 03KSE046
Installation costs	Euro/unit	500	HEAT, own calculations
Repair and maintenance costs	Euro/a	8.5	UBA (2014), FKZ 03KSE046
Uninstalling costs	Euro/unit	250	HEAT, own calculations
Annual electricity consumption	kWh/a	1307	according to product A
Electricity price	Euro/kWh	0.296	Oeko-Institut (2016)

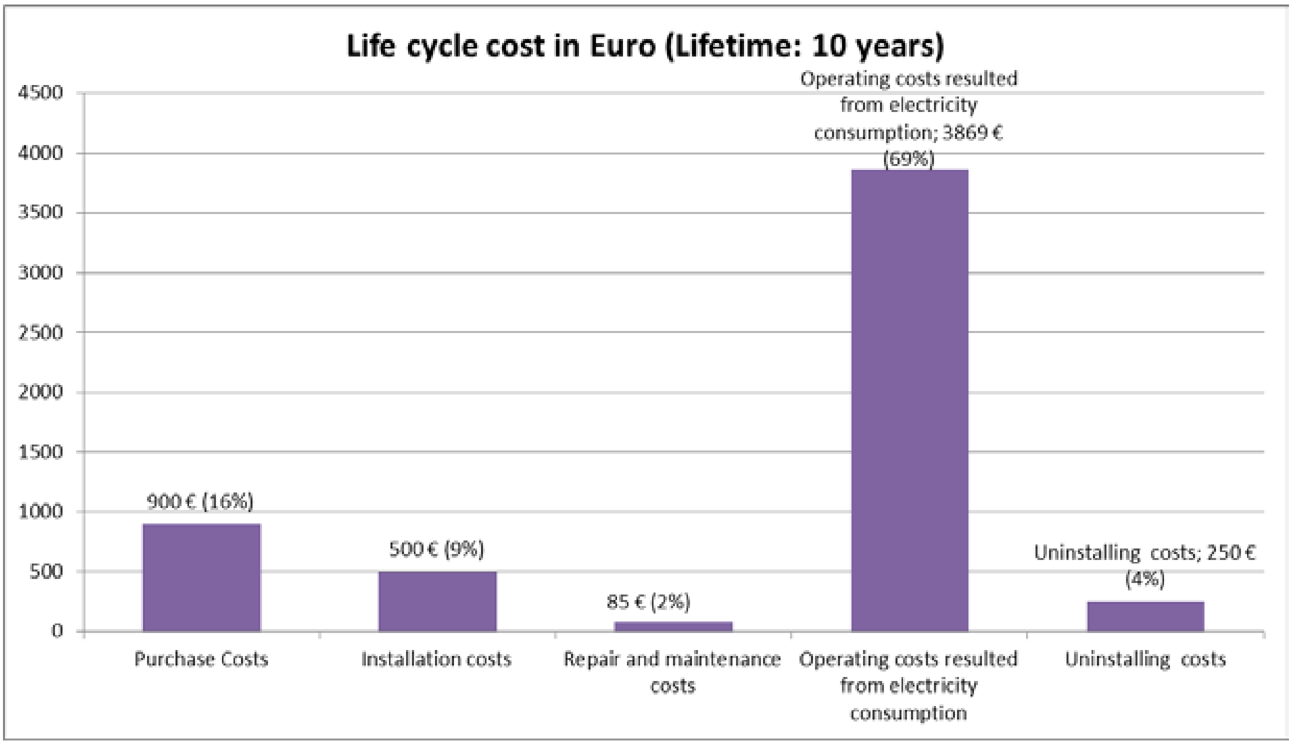
As average electricity price for Germany in 2015, 0.296 Euro per kWh are assumed (based on a literature review). Over a product life time of 10 years, this leads to energy consumption cost of 3.869 Euros, if the annual electricity consumption of product A with 1307 kWh per year is taken as a basis.

Table 42 and Figure 29 present the outcomes of the LCC calculations over the whole life time of an air conditioner.

Table 42: Results of the LCC calculation

LCC (Lifetime: 10 years)	Value (Euro)	Share (%)
Purchase Costs	900	16
Installation costs	500	9
Repair and maintenance costs	85	2
Operating costs resulted from electricity consumption	3869	69
Uninstalling costs	250	4
Total	5604	100

Figure 29: Estimated Life Cycle Costs (LCC) of an Air Conditioner



Source: Own illustration (Oeko-Institut)

Figure 29 shows that the operating costs amount to 69% of the total LCC, followed by the purchase costs (16%), installing and uninstalling costs (together 13%) and the maintenance costs (2%).

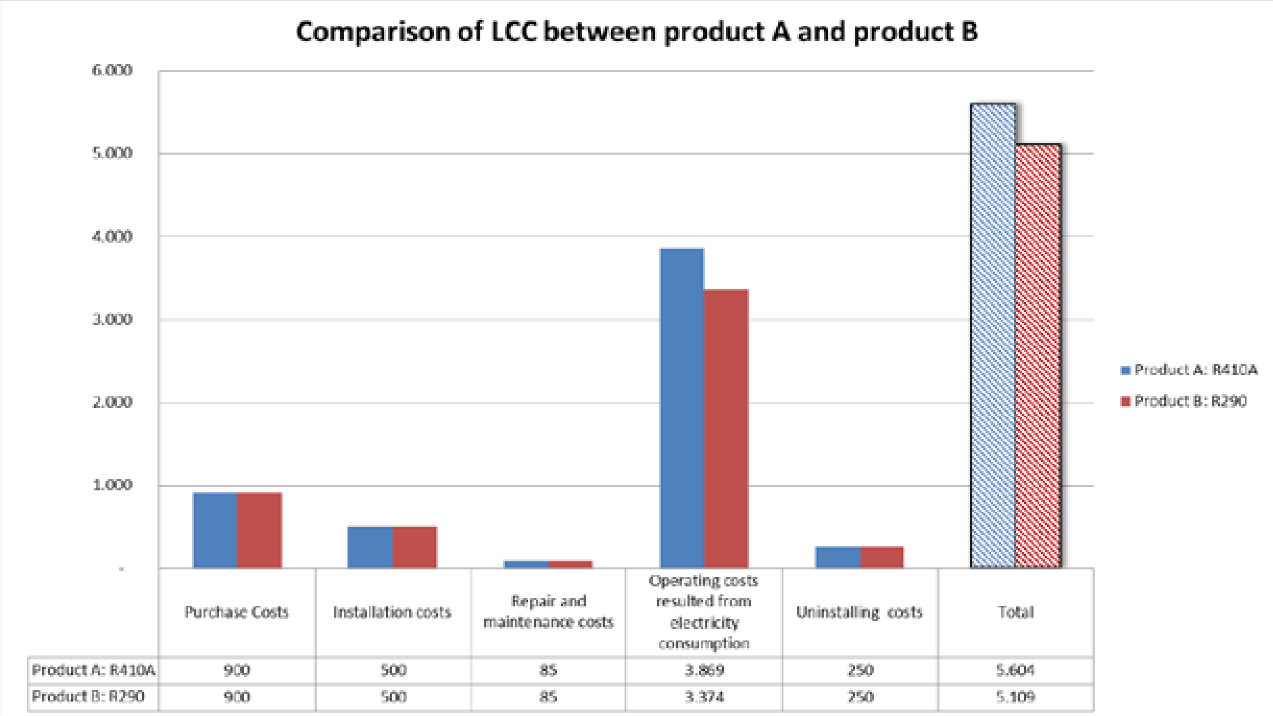
In order to show possible monetary savings of energy efficient of products, a comparison of the total life-cycle costs between product A and product B is conducted. Table 43 documents the considered costs for this comparison. Except the operating costs, that are strongly related with the electricity consumption in the use phase, the other costs are assumed to be equal.

The operating costs of product B are calculated based on the annual electricity consumption of 1140 kWh/a (Table 26). Figure 30 shows that the more energy efficient product in total saves around 500 Euros throughout the life span.

Table 43: Costs considered in the life cycle cost analysis of product A and product B

LCC (Lifetime: 10 years)	Product A: R410A	Product B: R290
Purchase Costs	900	900
Installation costs	500	500
Repair and maintenance costs	85	85
Operating costs resulted from electricity consumption	3.869	3.374
Uninstalling costs	250	250
Total	5.604	5.109

Figure 30: Comparison of Life Cycle Costs (LCC) between product A and product B



	Purchase Costs	Installation costs	Repair and maintenance costs	Operating costs resulted from electricity consumption	Uninstalling costs	Total
Product A: R410A	900	500	85	3.869	250	5.604
Product B: R290	900	500	85	3.374	250	5.109

Source: Own illustration (Oeko-Institut)

7 Legislation and standards

Highly relevant regulations which apply for single-split AC in Europe and Germany are:

- Commission Regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans (OJ L 72 of 10.3.2012, p. 7);
- Commission delegated regulation (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners (OJ L 178 of 6.7.2011, p. 1);
- Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated green-house gases and repealing Regulation (EC) No 842/2006 (OJ L 150 of 20.05.2014, p. 195).

Regulation (EU) No 206/2012 is an implementing regulation under the ecodesign directive and defines MEPS and sound power levels apart from various other details as minimum criteria to put air conditioners on the market, while Regulation (EU) No 626/2011 introduced energy labelling of air conditioners and defines different energy classes with appropriate SEER and SCOP values.

The Regulation (EU) No 517/2014 does not focus on natural refrigerants, however, indirectly promotes these substances and is consequently included here. This regulation includes four focal instruments:

- Limiting the total amount of the most important F-gases that can be sold in the EU (HFC phase down scheme):
- Banning the use of F-gases in many types of new equipment:
- Preventing emissions of F-gases from existing equipment (e.g. improved containment and recovery):
- Controlling the HFC imports of pre-charged equipment (part of the quota).

The most important instrument of the new F-gas Regulation, the phase down scheme, is limiting the total amount of HFC placed on the market. Thus HFCs are becoming increasingly expensive.

Producers and importers placing at least 100 tonnes of bulk CO_2e of HFCs on the market in a calendar year have to request a quota at the European Commission. But also manufacturers/importers who want to place pre-charged room air conditioners on the EU market, will have to apply for quotas and provide a certification of conformity. Consequently, the import of single-split AC, pre-charged with high GWP HFC refrigerants such as R-32 (GWP=675), will be increasingly difficult in the future. This is not only because of the reduced quotas, but also due to the expected price increase of HFCs. Particular the appliance sector is sensitive to changes in the price level.

Finally, there is a product ban for single-split systems from 01.01.2025, when the system contains less than 3 kg initial charge and operates with a refrigerant with GWP ≥750.

Regulation (EU) No 517/2014 also requires all personnel and companies to have a certification according to Regulation (EU) No 2015/2067[81], demonstrating their skill for proper installation, service and recovery of refrigerants, among others.

There are various other directives and standards that apply for single-split AC, the most relevant ones, including those mentioned in Regulation (EU) No 206/2012 and Regulation (EU) No 626/2011, can be found in Annex I (Chapter 11). With regard to the use of propane/propylene as flammable refrigerants, the most important standards, which represent a barrier for the use of these refrigerants are:

- ISO 5149: 2014 Refrigerating systems and heat pumps -- Safety and environmental requirements[82];
- DIN EN 378: 2012 Refrigerating systems and heat pumps - Safety and environmental requirements[83];
- DIN EN 60335-2-40: 2014 Household and similar electrical appliances[84].

The barrier is given by the formula described in DIN EN 378 and DIN EN 60335-2-40 (for "human occupied space for cooling or heating for human comfort"), limiting the maximum initial charge of flammable refrigerants (e.g. propane as an A3 refrigerant according to DIN EN 378), depending on the room area, the installation height of the indoor unit (evaporator), and the lower flammability limit (LFL) of the refrigerant (0.038 kg/m^3 in case of propane).

81 Commission implementing Regulation (EU) 2015/2067 of 17 November 2015 establishing, pursuant to Regulation (EU) No 517/2014 of the European Parliament and of the Council, minimum requirements and the conditions for mutual recognition for the certification of natural persons as regards stationary refrigeration, air conditioning and heat pump equipment, and refrigeration units of refrigerated trucks and trailers, containing fluorinated greenhouse gases and for the certification of companies as regards stationary refrigeration, air conditioning and heat pump equipment, containing fluorinated greenhouse gases (OJ L 301 of 18.11.2015, p.28)

82 http://www.iso.org/iso/catalogue_detail.htm?csnumber=54979

83 https://www.beuth.de/de/norm/din-en-378-1/151129166

84 https://www.beuth.de/de/norm/din-en-60335-2-40/194230842

The formula applies even though it lacks scientific evidence and assumes the entire refrigerant charge to enter the room in case of an accident. This assumption was shown to be invalid under the occurring pressure conditions (cf. Zhang 2013). There is a continuous review process of the standards within the standard committees.

Despite the restrictions, flammable refrigerants can be used in room air conditioners for cooling or heating. A room with a size of 30 m^2 would allow an air conditioning system with 0.4 kg propane as refrigerant. This is a charge size that can be realised with AC units that exhibit cooling capacities of less than 5 kW.

However, it is more difficult to realise the use of flammable refrigerants the higher the efficiency of air conditioners. This is given by the positive correlation between "specific charge" (i.e. kg of refrigerant per kW nominal cooling capacity) and SEER values: higher efficiency is often realised by increasing heat exchangers, which comes along with higher refrigerant charge.

It is noteworthy that the standards have an informative character only and are not legally binding. That is, manufacturers can deviate from the standards' recommendations, when demonstrating the lack of additional associated safety risks.

8 Comparison of legal requirements and selected Asian ecolabels

When comparing different ecolabels, it is important to differentiate between the legal requirements in the countries and the voluntary award criteria to receive the respective ecolabel. The legal framework was already introduced in Chapter 7, here specifications for specific parameters are given.

8.1 Legal requirements

Table 44 shows the legal requirements for air conditioners in China, Thailand, South Korea and the European Union[85]. The following specifications are considered: energy efficiency, noise and the use of hazardous substances.

[85] The authors cannot guarantee completeness of the legal requirements.

Table 44: Legal requirements for air conditioners in China, Thailand, South Korea and the European Union. To be completed with input from Asian countries

CRITERION	CHINA	INDIA	THAILAND	SOUTH KOREA	EUROPEAN UNION
Energy Efficiency	see below	see below	see below	see below	see below

CHINA

Title of standard:
GB 21455-2013 (2013): "The minimum allowable values of the energy efficiency and energy efficiency grades for variable speed room air conditioners"

Remarks: Compulsory MEPS & Label which does not apply to movable ACs, VRFs, and unitary ACs

RCC (kW)	SEER (Wh/Wh)					
	Grade I		Grade II		Grade III	
	Heat pump	Cooling only	Heat pump	Cooling only	Heat pump	Cooling only
≤ 4.50	4.50	5.40	4.00	5.00	3.50	4.30
4.50 < RCC ≤ 7.10	4.00	5.10	3.50	4.40	3.30	3.90
7.10 < RCC ≤ 14	3.70	4.70	3.30	4.00	3.10	3.50

INDIA

Title of standard:
BEE-Star Energy Efficiency Label

Remarks: Compulsory MEPS

	Energy Efficiency Ratio (W/W)	
	1/2014 - 12/2015 (Rev 2)	
Grade	Minimum RCC	Maximum RCC
1 Star	2.70	2.89
2 Star	2.90	3.09
3 Star	3.10	3.29
4 Star	3.30	3.49
5 Star	3.50	

THAILAND

Title of standard:
TIS 2134-2553 (2010): "Room air conditioners: environment requirements: energy efficiency"

Remarks: Compulsory MEPS

RCC (kW)	EER (W/W)	
	Window-Type	Split-Type
≤ 8.00	2.82	2.82
8.00 < RCC ≤ 12.00	2.53	2.82

EGAT Label no.5: "Label no.5 air conditioner"

Remarks: Voluntary Label for variable speed air conditioner

RCC (kW)	SEER (Wh/Wh)
≤ 8.00	≥ 4.40
8.00 < RCC ≤ 12.00	≥ 4.10

SOUTH KOREA

Title of standard:
TIS 2134-2553 (2010): "Room air conditioners: environment requirements: energy efficiency"

Remarks: Compulsory MEPS & Label

	RCC (kW)	EER (W/W)
Window-type	All RCCs	2.88
Split-type	< 4.00	3.37
	4.00 ≤ RCC < 10.00	2.97
	10.00 ≤ RCC < 17.50	2.76
	17.00 ≤ RCC < 23.00	2.63

Energy Efficiency Label: Split type, 4.0 kW ≤ RCC < 10.0 kW (without network function)

EER (W/W)	Standby power *	Level
4.40 ≤ EER	≤ 1. 00 W	1
4.40 ≤ EER	N/A	2
3.86 ≤ EER < 4.40	N/A	3
3.39 ≤ EER < 3.86	N/A	4
2.97 ≤ EER < 3.39	N/A	5

* (Off mode power consumption)

EUROPEAN UNION

Title of standard:
Regulation (EU) No. 206/2012: "ecodesign requirements for air conditioners and comfort fans"

Remarks: Compulsory MEPS

	SEER	SCOP
GWP of refrigerant > 150 for < 6 kW	4.60	3.80
GWP of refrigerant ≤ 150 for < 6 kW	4.14	3.42
GWP of refrigerant > 150 for 6-12 kW	4.30	3.80
GWP of refrigerant ≤ 150 for 6-12 kW	3.87	3.42

Regulation (EU) No. 626/2011: "Energy labelling of air conditioners"

Remarks: Compulsory Label

<table>
<tr><th>CRITERION</th><th>CHINA</th><th>INDIA</th><th>THAILAND</th><th>SOUTH KOREA</th><th>EUROPEAN UNION</th></tr>
<tr><td></td><td></td><td></td><td></td><td>Energy Efficiency Label: Split type, RCC < 4.0 kW (without network function)
<table>
<tr><td>EER (W/W)</td><td>Standby power *</td><td>Level</td></tr>
<tr><td>4.36 ≤ EER</td><td>≤ 1, 00 W</td><td>1</td></tr>
<tr><td>4.36 ≤ EER</td><td>N/A</td><td>2</td></tr>
<tr><td>4.00 ≤ EER < 4.36</td><td>N/A</td><td>3</td></tr>
<tr><td>3.67 ≤ EER < 4.00</td><td>N/A</td><td>4</td></tr>
<tr><td>3.37 ≤ EER < 3.67</td><td>N/A</td><td>5</td></tr>
</table>
* (Off mode power consumption)</td><td>
<table>
<tr><td>Energy Effi-ciency Class</td><td>SEER</td><td>SCOP</td></tr>
<tr><td>A+++</td><td>SEER ≥ 8.50</td><td>SCOP ≥ 5,10</td></tr>
<tr><td>A++</td><td>6.10 ≤ SEER < 8.50</td><td>4,60 ≤ SCOP < 5,10</td></tr>
<tr><td>A+</td><td>5.60 ≤ SEER < 6.10</td><td>4,00 ≤ SCOP < 4,60</td></tr>
<tr><td>A</td><td>5.10 ≤ SEER < 5.60</td><td>3,40 ≤ SCOP < 4,00</td></tr>
<tr><td>B</td><td>4.60 ≤ SEER < 5.10</td><td>3,10 ≤ SCOP < 3,40</td></tr>
<tr><td>C</td><td>4.10 ≤ SEER < 4.60</td><td>2,80 ≤ SCOP < 3,10</td></tr>
<tr><td>D</td><td>3.60 ≤ SEER < 4.10</td><td>2,50 ≤ SCOP < 2,80</td></tr>
<tr><td>E</td><td>3.10 ≤ SEER < 3.60</td><td>2,20 ≤ SCOP < 2,50</td></tr>
<tr><td>F</td><td>2.60 ≤ SEER < 3.10</td><td>1,90 ≤ SCOP < 2,20</td></tr>
<tr><td>G</td><td>SEER < 2.60</td><td>SCOP < 1,90</td></tr>
</table></td></tr>
</table>

<table>
<tr><th>CRITERION</th><th>CHINA</th><th>INDIA</th><th>THAILAND</th><th>SOUTH KOREA</th><th>EUROPEAN UNION</th></tr>
<tr><td>Refrigerant</td><td></td><td></td><td></td><td></td><td>Regulation (EU) No 517/2014
· The phase-down of HFC is the most important instrument within the new Regulation (EU) No 517/2014
· Producers and importers placing at least 100 tonnes of bulk CO_2e of HFCs on the market in a calendar year have to request a quota at the European Commission
· Manufacturers/importers who want to place room air conditioners on the EU market, will have to apply for quotas and provide a certification of conformity.
· Ban of single-split AC (<3 kg initial charge) with GWP ≥750 from 01.01.2025
Regulation (EU) No 1005/2009
· HCFC-22 forbidden in new installations since 01.01.2000
· Recycled HCFC-22 for maintenance of systems allowed until 01.01.2015
· Prohibition of using HCFC-22 either recycled or not from 01.01.2015</td></tr>
<tr><td>Noise (sound pressure level)</td><td></td><td></td><td></td><td></td><td>Title: Regulation (EU) No. 206/2012: “Ecodesign requirements for air conditioners and comfort fans”

Remarks: Compulsory standard

<table>
<tr><th rowspan="2">RCC (kW)</th><th colspan="2">Sound power level dB(A)</th></tr>
<tr><th>Indoor unit</th><th>Outdoor unit</th></tr>
<tr><td>≤ 6</td><td>≤ 60</td><td>≤ 65</td></tr>
<tr><td>6 < RCC ≤ 12 kW</td><td>≤ 65</td><td>≤ 70</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>CRITERION</th><th>CHINA</th><th>INDIA</th><th>THAILAND</th><th>SOUTH KOREA</th><th>EUROPEAN UNION</th></tr>
<tr><td>Hazardous substances</td><td>GB/T 16288-2008
Marking of plastics products

GB/T 18455-2010
Package Recycling Marks

GB/T 20861-2007
Terminology of waste product recovery

GB/T 26572-2011
Concentration limit requirements for certain restricted substances in electrical and electronic products

HJ/T 239-2006
Technical requirement for environmental labeling products Hg-free dry cells and batteries</td><td></td><td>TIS 1310
Symbols for recycling plastics</td><td>The Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles</td><td>Title: Directive 2011/65/EU “Restriction of the use of certain hazardous substances (RoHS)”

<table><tr><th>Substance</th><th>Amount (wt%)</th></tr><tr><td>Pb</td><td>≤ 0.1</td></tr><tr><td>Cd</td><td>≤ 0.01</td></tr><tr><td>Hg</td><td>≤ 0.1</td></tr><tr><td>Cr6+</td><td>≤ 0.1</td></tr><tr><td>PBB</td><td>≤ 0.1</td></tr><tr><td>PBDE</td><td>≤ 0.1</td></tr></table></td></tr>
</table>

8.2 Award criteria for selected Asian ecolabels

Table 45: Specifications and award criteria for selected Asian Ecolabels.

<table>
<tr><th>CRITERION</th><th>CHINA</th><th>THAILAND</th><th>SOUTH KOREA</th></tr>
<tr><td>Name of ecolabel</td><td>HJ 2535-2013</td><td>TGL-07-R3-15</td><td>EL-401</td></tr>
<tr><td>Scope</td><td>Applicable to:
· condensers using wind cooling and air cooling
· fully-enclosed motor-compressors
· room air conditioners for domestic or relevant uses with refrigerating capacity of and below 14,000 W
Not applicable to:
· movable air conditioners
· packaged terminal air conditioners
· separated units that cannot be composed into a complete refrigerating system
· air conditioners utilizing vapour absorption in their refrigeration cycle</td><td>Applicable to:
· Room air conditioners using air-cooled condensers or air-combined with water-cooled condenser, for the purpose of reducing temperature and humidity
· Air conditioners with the purpose of increasing temperature and humidity is excluded
· The cooling capacity of the room air conditioner under the criteria does not exceed 12,000 W, alternating current (AC), used with single or three-phase power supply.</td><td>Applicable to:
The criteria shall apply to general purpose air conditioners that use electricity as a power source and prepare system of refrigerant compressor used in households and offices. This shall include ‘single package type’ and ‘split type’.</td></tr>
<tr><td>Technical definition: Room air conditioner</td><td>Refers to a kind of device, which directly provides processed air to enclosed space, room or area. It mainly includes refrigerating systems for cooling and dehumidifying, and air circulation and cleaning units. Heating and ventilation devices can also be included, which can be assembled into a separate shell or designed as a component. For instance, air conditioners with free air supply, water source heat pump units, self-contained air conditioners, duct-type air conditioners, multi-connected air condition units, rooftop air condition units, and so on.</td><td>Air conditioners according to TIS 385 or TIS 1155

Unofficial translation from TIS 2134-2545; source: http://www.tisi.go.th/images/notif_th/fulltext/ttha104.pdf):
TIS 1155: Split-type room air conditioner: room air conditioner of split type as TIS 1155 which carry out cooling by means of air circulation and consists of condensing unit and fan-coil unit operated together. After mount in accordance with manufacturer's design, it will be able to cool and dehumidify the air of room or zone in which fan-coil is installed.</td><td>“Single package types”: main components such as a compressor, ventilator, heat exchanger, etc. are equipped in one cabinet.

“Split types”: main components such as a compressor, ventilator, heat exchanger, etc. are equipped in more than 2 cabinets.</td></tr>
<tr><td>Energy efficiency</td><td>Reference to: requirements of national energy efficiency standards</td><td>Reference to: requirements of Electricity Generating Authority of Thailand (EGAT) Label No. 5</td><td>Reference to: requirements for the first class energy efficiency rating according to the Energy Use Rationalization Act.</td></tr>
<tr><td>Refrigerant</td><td>Requirements for the refrigerant in use:<table><tr><td>Type of refrigerant</td><td>ODP</td><td>GWP</td></tr><tr><td>not specified</td><td>0</td><td>not specified</td></tr></table></td><td>Requirements for the refrigerant in use:<table><tr><td>Type of refrigerant</td><td>ODP</td><td>GWP</td></tr><tr><td>non-CFC</td><td>≤ 0.5*</td><td>≤ 2500</td></tr></table>*shall be 0 from Jan 1, 2017</td><td>Requirements for the refrigerant in use:<table><tr><td>Type of refrigerant</td><td>ODP</td><td>GWP</td></tr><tr><td>Not specified</td><td>shall be 0</td><td>≤ 2500</td></tr></table></td></tr>
</table>

CRITERION	CHINA	THAILAND	SOUTH KOREA

Noise (sound pressure level)

CHINA

RCC (kW)		Sound pressure level dB(A)
≤ 2.5	Indoor unit	39
	Outdoor unit (static pressure)	40
	Outdoor unit	49
> 2.5~4.5	Indoor unit	41
	Outdoor unit (static pressure)	42
	Outdoor unit	52
> 4.5~7.1	Indoor unit	43
	Outdoor unit (static pressure)	44
	Outdoor unit	56
> 7.1	Indoor unit	47
	Outdoor Unit (static pressure)	48
	Outdoor unit	59

THAILAND

	RCC (kW)	Sound pressure level dB(A)	
		Indoor unit	Outdoor unit
Non-split-type	All RCCs	≤ 55	≤ 60
Split-type	≤ 8 kW	≤ 50	≤ 57
	8 kW < RCC ≤ 12 kW	≤ 57	≤ 63

SOUTH KOREA

	RCC (kW)	Noise Standards* dB(A)	
		Indoor unit	Outdoor unit
Single package	All RCCs	≤ 55	≤ 60
Split-type	RCC < 4 kW	≤ 45	≤ 55
	4 kW ≤ RCC < 10 kW	≤ 50	≤ 60
	10 kW ≤ RCC < 35 kW	≤ 55	≤ 65
	RCC ≥ 35 kW	≤ 55	≤ 70

* Sound pressure level (assumption of the authors, compare with TGL-07-R3-15 (Thailand)

Hazardous substances in components and parts

CHINA

- Plastic components with a weight of over 25 g or surface area of over 200 mm², shall be made from a single type of polymer or co-polymer

- Plastic component with a weight of over 25 g and surface area of over 200 mm² shall be marked (see GB/T 16288 [GB/T 16288-1996 Marking for plastic packaging products recycling]).

- The limitation requirements of restricted substances shall meet the relevant requirement of GB/T 26572 [GB/T 26572- Requirements of concentration limits for certain restricted substances in electrical and electronic products]

- Short-Chain Chlorinated Paraffins (SCCPs) are not allowed to be used in the base material of the product shell and circuit board. The content of SCCPS shall be less than 1% of the total weight of the plastic components

- The plastic components of the product shell, which are over 25 g in weight, shall not use chlorine and bromine polymers. And fire retardants containing organic chloride or organic bromide are not allowed to be added

- Except for the electric wires and cables, plastic compo-

THAILAND

- Plastic parts with a weight of ≥ 25 g shall not contain heavy metals or their compounds, and flame retardants (Table below)

- Plastic parts with a weight of ≥ 25 g or having surface area from 200 mm² shall be marked for the type of plastic (see TIS 13107, or ISO 10438, or ISO 114699)

- Paints applied to the product shall not contain heavy metals or their compounds including mercury (Hg), lead (Pb), cadmium (Cd), and hexavalent chromium (Cr6+). The total contamination of Hg, Pb, Cd and Cr6+ shall not exceed 0.1% (1000 ppm) by weight.

The content of hazardous substances shall comply with following requirements:

Substance	Heavy metal or its compound				Flame retardant	
Amount (ppm)	Pb	Cd	Hg	Cr6+**	PBB	PBDE
	≤ 1000	≤ 100	≤ 1000	≤ 1000	≤ 1000	≤ 1000

** If the total chromium (Cr) is less than or equal to 1000 ppm, it implies that Cr6+ has met the requirement.

SOUTH KOREA

- Lead, cadmium, mercury and their compounds, and hexavalent chromium compounds shall not be used in the product.

- Content of lead, cadmium, mercury and hexavalent chromium 6+ in the parts of the product shall comply with one of the following criteria.

- PBBs (polybrominated biphenyls), PBDEs (polybrominated diphenylethers) and short chain chlorinated paraffin (C= 10~13) whose chlorine concentration is 50% or more shall not be used in the product.

a) the applicant shall have an appropriate system to control the content of hazardous substances as following requirements.

b) Provided that the applicant does not have an appropriate system for the control of hazardous substances, the content of hazardous substances in the parts of the product shall comply with the following requirements. In case the content of total chromium (Cr) is 1000 mg/kg or less, it (Cr6+) is regarded as equivalent.

<table>
<tr><th>CRITERION</th><th>CHINA</th><th>THAILAND</th><th>SOUTH KOREA</th></tr>
<tr><td></td><td>nents over 25 g shall not use the Phthalates listed in the Appendix A as plasticizer
- In the shell of the remote control, all kinds of buttons, filters and external power lines included, the total amount of benzo[a]pyrene shall not exceed 20 mg/kg, and the total amount of the 18 Polycyclic Aromatic Hydrocarbons (PAHs) listed in Appendix B shall not exceed 200 mg/kg
- The dry cells within the products shall meet requirements of HJ/T 239 [HJ/T 239- Technical requirement for environmental labelling products Hg-free dry cells and batteries]</td><td></td><td><table><tr><td>Substance</td><td colspan="4">Heavy metal or its compound</td></tr><tr><td rowspan="2">Amount (mg/kg)</td><td>Pb</td><td>Cd</td><td>Hg</td><td>Cr6+**</td></tr><tr><td>≤ 1000</td><td>≤ 100</td><td>≤ 1000</td><td>≤ 1000</td></tr></table></td></tr>
<tr><td>Recyclable design; Recycling and disposal</td><td>- Recyclability Rate: refers to the percentage of the weight of the part which can be recycled and reused, divided by the total weight. (GB/T 20861-2007) [GB/T 20861- Terminology of waste product recovery]
- The recyclability rate of the product should not be lower than 83%
- Instructions for the recycling and disposal shall be provided</td><td>- Plastic parts of the product shall be recyclable at least 80% of total plastic weight of the product.</td><td>- According to the ‘Act on Material Recycling of Electrical, Electronic Products and Automobiles’, recycling rate of the product shall be over 80% of its weight.
- With respect to use of chemical substances in manufacturing process and recyclability of the parts of the product at disposal stage, the product shall comply with the following requirements.
Note: This Criteria shall not applied on materials which are exempted from Hazardous Substances Restriction lists on EU Directive 2002/95/EC and lead in solder of printed circuit board (PCB). However, in case of revision of EU Directive 2002/95/EC, this shall follow revised EU Directive which is applicable at the time the application for eco-label certification.
- With respect to recycling in the manufacturing process or recyclability of the product in disposal, the following requirements shall be satisfied.
- Separable plastic parts (weighing 25 g or more and covering a flat surface of 200 mm^2 or more) shall be visibly marked with material identification to facilitate separation and collection in disposal.
- Applicants shall establish and implement a collecting and recycling system for waste products (including shock-absorbing material for packaging). In case that an applicant manages the system by assigning a specialized company, submission of relevant documents proving it shall be a sufficient proof of compliance.</td></tr>
</table>

CRITERION	CHINA	THAILAND	SOUTH KOREA
Packaging	- HCFCs are not allowed to be used as foaming agent - The total amount of heavy metal lead, cadmium, mercury and hexavalent chromium shall not exceed 100 mg/kg in the package and packaging materials - Marks shall be attached according to standard GB/T 18455 [GB/T 18455- Package Recycling Marks]	- Paper packaging shall be made from 100% recycled pulp for corrugating medium paper, and shall not be less than 85% recycled pulp for Kraft liner board paper. - Plastic packaging shall be marked for the type of plastic according to TIS 1310, or ISO 1043, or ISO 11469 - Plastic packaging shall not contain halogenated hydrocarbon. - Shock absorbing material such as EPS (expanded polystyrene), EPE (expanded polyethylene), and EPP (Expanded polypropylene), and blowing agent, used with the packaging of the product shall have ODP of zero.	- Shock-absorbing materials in packaging shall be made of recycled pulp or paper such as pulp mold. However, following materials are regarded as equivalent. a) Shock-absorbing materials certified according to 'EL 606. Packaging Materials' b) Shock-absorbing materials manufactured by using more than 50wt% of recycled plastics c) EPS (expanded polystyrene), EPE (expanded polyethylene) and EPP (expanded polypropylene) whose foaming agent has zero ODP d) Air cell packing bubble wrap that injects air into synthetic resin.
Production	- A Recovery unit for the refrigerant shall be equipped - HCFCs, 1,1,1-trichloroethane ($C_2H_3Cl_3$), trichloroethylene (C_2HCl_3), dichloroethane (CH_3CHCl_2), dichloromethane (CH_2Cl_2), trichloromethane ($CHCl_3$), tetrachloromethane (CCl_4),and 1-bromopropane (C_3H_7Br) are not allowed to be use as cleaning solvent - Lead-free welding shall be adopted in the process of component assembly and attachment - In the pretreatment process of sheet metal parts, phosphorous degreasing agents and phosphating agents are not allowed to be used		To reduce environmental impact through its life cycle, the product shall be designed and produced in consideration of resource and energy-saving, reducing pollutants and hazardous substance use, using recycled materials, improving recyclability and durability, etc.
User manual, consumer information	The owner's manual shall be handed to the user together with the product, including the following information: a) Operation and maintenance instructions b) Introduction about stand by time and a reminder that zero energy consumption can only be achieved if the product is not connected with the input power c) A reminder to set the temperature correctly: 2°C lower than the desired value when heating, and 2°C higher when cooling, so as to save energy d) When using the air conditioner, please avoid direct sunlight into the room, and do not open and close the windows and doors frequently e) Please clean the filter frequently f) The manufacturing enterprise shall provide repairable and replaceable components and parts of the product during the whole duration of its lifespan, so as to guarantee that the product can function well during its lifespan	- Name plate attached to the product shall contain the detail according to TIS 2134 - User manual shall be provided in Thai and consist of the instruction of maintenance and proper use of the product in order to maximize the lifetime and energy saving, include: • Turn off the air conditioner when do not use • Turn off the ventilation fan if not necessary • Suggestion for setting the temperature of air conditioner not to be lower than 25°C	- Indication of matters contributing to reasons (energy-saving, low level of noise emission, environment-friendly product design) for the certification of the concerned product at the stage of consumption - Guide for method of collection of waste products (phone number of collection companies and etc.)

CRITERION	CHINA	THAILAND	SOUTH KOREA
Testing methods	- Test for item 5.3.2.1 of technical content shall be conducted in accordance with the corresponding methods, stipulated in the energy efficiency standard of each product - Test for item 5.3.3 of technical content shall be conducted in accordance with the corresponding methods, stipulated in the standard of each product - The remaining items of technical content shall be tested via document review, supported by on-site visits	- The product shall be certified according to TIS 21341 and TIS 3852, or TIS 11553 or passed the test according to the mentioned standards Verification method: The applicant shall submit a copy of TIS certificate, or test report according to the mentioned TIS standards - The product shall be certified or passed the test according to TIS 1529 or IEC 60335-2-40, or equivalent standards Verification method: The applicant shall submit a certificate, or test report according to TIS 15294 or IEC 60335-2-405 or equivalent to standards - Manufacturing, transportation and waste disposal from the manufacturing process shall be in accordance with the national laws and regulations Verification method: The applicant shall submit evidences to prove that manufacturing, transportation and waste disposal from the manufacturing process comply with the requirement - Testing laboratories shall be owned by the government, or recognized by the government according to Article 5 of the Industrial Product Standard Act B.E. 2511, or accredited for TIS 1702517 or ISO/IEC 1702518. - Test report according to the methods mentioned in TGL product criteria: If the applicant would like to submit a test report which was conducted by other methods which might be equivalent to the method mentioned in the TGL criteria, the applicant shall submit the following documents with the test report include 1) A certificate issued by the laboratory which the product was tested, showing that the test method conducted with the TGL applied product is equivalent to the method specified in the TGL criteria. 2) A document showing comparison between the test method which the applicant used and the method specified in the TGL criteria document. - shall be valid within one year after the issued date - Self-declaration letters shall be valid within one year after the issued date. - Self-declaration letters shall be signed by the authorized person, and sealed (if applicable).	- Hazardous substances: Verification of submitted documents; the test method is described within the criteria - Energy consumption and noise reduction: Test report or certification by an accredited testing laboratory in accordance with 'regulations on management of efficiency control equipment in accordance with the Energy Use Rationalization Act. Test report by an accredited testing laboratory in accordance with the KS C 9306(Air Conditioners) Note: If the noise is gauged in a non-anechoic room, the distance between walls and the tested product shall be broad enough not to create reflecting sounds. A gap between background noise and gauged noise shall be at least more than 10 dB(A). - Recyclability and disposal: Verification of submitted documents Quality criteria: Test report by an accredited testing laboratory in accordance with KS C 9306 (Air Conditioners) or the safety standards for electric appliances or certificate of equivalent Consumer information: Verification of submitted documents

9 Award criteria

Based on the previous analysis and research, the following award criteria have been defined:

Basic Criteria for Award of the Environmental Label

Stationary air conditioners

RAL-UZ 204

Edition August 2016

RAL gGmbH

Siegburger Straße 39, 53757 Sankt Augustin, Germany, Telephone: +49 (0) 22 41-2 55 16-0

Fax: +49 (0) 22 41-2 55 16-11

Internet: www.blauer-engel.de, e-mail: umweltzeichen@RAL-gGmbH.de

Table of contents

1 Introduction

1.1 Preface

In cooperation with the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, the Federal Environmental Agency (UBA) and considering the results of the expert hearings conducted by RAL gGmbH, the Environmental Label Jury has set up these Basic Criteria for the Award of the Environmental Label. RAL gGmbH has been tasked with awarding the Environmental Label. Upon application to RAL gGmbH and on the basis of a Contract on the Use of the Environmental Label to be concluded with RAL gGmbH, the permission to use the Environmental Label may be granted to all products and services, provided that they comply with the requirements as specified hereinafter.

1.2 Background

Air conditioners are designed to control the thermal comfort of living and working rooms and are especially used in those countries that regularly experience high outdoor temperatures. In those countries with very high outdoor temperatures, air conditioners are responsible for around one third of the greenhouse gas emissions (IEA 2008). Yet an increased use of air conditioners in Germany, in parallel with more frequent hot spells, is also expected. The number of days on which the air temperature reaches 30 degrees Celsius or more has already increased today by eight days since 1950 (German National Meteorological Service, Annual Report on Climate and Environment). The number of hot days will continue to increase in the future due to progressive global warming. In order to guarantee productive working conditions, it is considered necessary to keep indoor office temperatures below 26 degrees Celsius[86], with employers expected to achieve this through the increased use of air conditioners.

Air conditioners contribute to climate change in two respects: firstly through their electricity consumption and the greenhouse gas emissions associated with energy generation (indirect emissions) and secondly through direct emissions of refrigerants that themselves often have a very high global warming potential (GWP).

86 Limit for the operative room temperature in air-conditioned buildings, class B according to DIN EN ISO 7730, also see the German Technical Rules for Workplaces ASR A3.5.

Against this background, the use of environmentally friendly and energy efficient air conditioners could reduce greenhouse gas emissions. The key focus is placed here on the use of natural refrigerants and increasing the efficiency of the devices. An indicative life cycle assessment, completed as part of the development process for these Basic Award Criteria for the use of air conditioners in Germany, illustrated that environmentally friendly and energy efficient air conditioners using the refrigerant propane (R290) generate around 30% less greenhouse gas emissions than conventional devices using the refrigerant R410A. This savings potential is significantly higher in those countries with higher outdoor temperatures and an energy generation system based primarily on fossil fuels – as is the case for example in Asia.

1.3 Objective of the environmental label

Climate protection, a reduction in power consumption, the minimisation of greenhouse gas emissions and the avoidance of pollutants are key objectives of environmental protection.

The Blue Angel ecolabel for “stationary air conditioners” may be awarded to products featuring the following environmental properties:

- High energy efficiency
- Low emissions of greenhouse gases
- Low noise emissions
- Reduced pollutant contents

In addition, the requirements set by the environmental label should ensure that suppliers of air conditioners provide services of a high professional quality.

1.4 Compliance with legal requirements

The observance of relevant existing laws and legal requirements is a prerequisite for those products awarded with the environmental label. In particular, the following legal requirements are observed:

- Commission Regulation (EC) No. 206/2012[87] for air conditioners and comfort fans
- Commission Delegated Regulation (EU) No. 626/2011 on the energy labelling of air conditioners [88]

[87] Commission Regulation (EC) No. 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans

Commission Implementing Regulation (EU) 2015/2067[89]

Operational Safety Ordinance (BetrSichV)[90]

Technical Rules for Operational Safety (TRBS)[91]

Technical Rules for Hazardous Materials (TRGS)[92]

In addition, building regulations in the German federal states must be complied with.

1.5 Definitions

Air conditioner means a device capable of cooling and/or heating indoor air, using a vapour compression cycle driven by an electric compressor, including air conditioners that provide additional functionalities such as dehumidification, air-purification, ventilation or supplemental air-heating by means of electric resistance heating, as well as appliances that may use water (either condensate water that is formed on the evaporator side or externally added water) for evaporation on the condenser, provided that the device is also able to function without the use of additional water, using air only.[93]

Seasonal energy efficiency ratio (SEER) is the overall energy efficiency ratio of the unit, representative for the whole cooling season and is calculated as the reference annual cooling demand divided by the annual electricity consumption for cooling.[9]

Seasonal coefficient of performance (SCOP) is the overall coefficient of performance of the unit, representative for the whole designated heating season (the value of

---

88 Commission Delegated Regulation (EU) No. 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners

89 Commission Implementing Regulation (EU) 2015/2067 of 17 November 2015 establishing, pursuant to Regulation (EU) No 517/2014 of the European Parliament and of the Council, minimum requirements and the conditions for mutual recognition for the certification of natural persons as regards stationary refrigeration, air conditioning and heat pump equipment, and refrigeration units of refrigerated trucks and trailers, containing fluorinated greenhouse gases and for the certification of companies as regards stationary refrigeration, air conditioning and heat pump equipment, containing fluorinated greenhouse gases

90 Ordinance on safety and health protection in the use of working materials (BetrSichV), Operational Safety Ordinance from 3 February 2015 (BGBl. I p. 49), which was changed by Article 1 of the Ordinance from 13 July 2015 (BGBl. I P. 1187)

91 http://www.baua.de/de/Themen-von-A-Z/Anlagen-und-Betriebssicherheit/TRBS/TRBS.html

92 http://www.baua.de/de/Themen-von-A-Z/Gefahrstoffe/TRGS/TRGS.html

93 Definitions in accordance with: Regulation (EC) No. 206/2012.

SCOP pertains to a designated heating season) and is calculated as the reference annual heating demand divided by the annual electricity consumption for heating. [9]

Rated capacity (P_{rated}) means the cooling or heating capacity of the unit at standard rating conditions. [9]

2 Scope

These Basic Award Criteria are valid for air conditioners for stationary use with the following characteristics:

- The air conditioners must be fitted with an electrically driven compressor.
- The devices must have a cooling function or both a cooling and a heating function.
- The rated capacity of the devices must not exceed a value of 12 kW.
- The devices must fall under the scope of validity of EU Regulation No. 206/2012[94].

The following do not fall under the scope of these Basic Award Criteria:

- Monoblock devices, meaning air conditioners that are described as "single duct air conditioners" or "double duct air conditioners" in Regulation (EU) No. 206/2012, and window air conditioners ("window type" and "through-the-wall" devices).
- Air conditioners that exclusively provide the functions of dehumidification, air-purification, ventilation or air-heating according to Regulation (EU) No. 206/2012.
- Air conditioners for use in vehicles.

[94] *Commission Regulation (EC) No. 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans*

3 Requirements

3.1 Energy efficiency

3.1.1 Seasonal energy efficiency ratio

The air conditioners must have a seasonal energy efficiency ratio (SEER) for an average climate that fulfils the following requirements:

$$SEER \geq 7$$

Compliance verification

The applicant shall declare compliance with the requirements in Annex 1 to the Contract and submit the corresponding pages of the product documentation in accordance with Regulation (EU) No. 206/2012, Annex 1 Number 3(c) as Annex 6 to the Contract, in which the SEER value for an average climate is documented. In addition, the applicant shall submit a test report from a testing institution accredited according to DIN EN ISO/IEC 17025 as Annex 2, which demonstrates the calculation of the SEER value in accordance with the stated measurement guidelines in Regulation (EU) No. 206/2012. Test reports completed by the applicant are recognised as being of an equivalent standard when the testing laboratory used for the measurements is accredited by an independent body as an SMT laboratory (supervised manufacturer testing laboratory).

It is possible to provide compliance verification based on product families ("Basic Model Groups") according to the Eurovent Certification[95]*.*

3.1.2 Seasonal coefficient of performance

If the air conditioner also has a heating function, the seasonal coefficient of performance (SCOP) for an average climate must comply with the following requirements:

[95] According to the Eurovent certification, product families ("Basic Model Groups" or BMG) are defined by units which are essentially the same in terms of their cooling and heating performance (+/-10%) and function (cooling or heating) and which are the same or comparable in terms of their basic components, specifically fans, heat exchangers, compressors and motors, according to EUROVENT (2015) Operational Manual for the Certification of Air Conditioners, http://www.eurovent-certification.com/fic_bdd/en/1435237711_OM-1-2015_AC.pdf (accessed on: 18.05.2016).

SCOP ≥ 4.6

Compliance verification

The applicant shall declare compliance with the requirements in Annex 1 to the Contract and submit the corresponding pages of the product documentation in accordance with Regulation (EU) No. 206/2012, Annex 1 Number 3(c) as Annex 6 to the Contract, in which the SEER value for an average climate is documented. In addition, the applicant shall submit a test report from a testing institution accredited according to DIN EN ISO/IEC 17025 as Annex 3, which demonstrates the calculation of the SCOP value in accordance with the stated measurement guidelines in Regulation (EU) No. 206/2012. Test reports completed by the applicant are recognised as being of an equivalent standard when the testing laboratory used for the measurements is accredited by an independent body as an SMT laboratory (supervised manufacturer testing laboratory).

It is possible to provide compliance verification based on product families ("Basic Model Groups") according to the Eurovent Certification[11].

3.2 Refrigerant

The air conditioner must be free of refrigerants containing halogens. In addition, it is not permitted to use ammonia as a refrigerant.

Compliance verification

The applicant shall declare compliance with the requirements and state the ODP value, the GWP value and the chemical name of the refrigerant used in Annex 1 to the Contract.

3.3 Air filter

The indoor units of the devices (evaporator) must be fitted with air filters that can be easily cleaned. The cleaning process can either be completed by an automatic cleaning function or manually by the user themselves. Cleaning of the heat exchanger in the outdoor units (condenser) should be carried out by qualified personnel and this process should be possible without the use of special tools. The cleaning process (indoor units) must be described in the operating instructions, while they should also refer the user to corresponding trained specialists for cleaning the heat exchangers in the outdoor units.

Compliance verification

The applicant shall declare compliance with the requirements in Annex 1 to the Contract and submit the corresponding product documentation which describes the cleaning of the filter as Annex 6.

3.4 Noise emissions

The noise emissions of the devices must comply with the following requirements:

Rated capacity (P_{rated}) in cooling or heating operation	**Requirements for the sound power level at rated capacity**	
	Indoor units	**Outdoor units**
≤ 4.5 kW	≤ 50 dB(A)	≤ 58 dB(A)
4.5 kW < P_{rated} ≤ 6 kW	≤ 55 dB(A)	≤ 62 dB(A)
6 kW < P_{rated} ≤ 12 kW	≤ 58 dB(A)	≤ 68 dB(A)

.

The noise emissions must be stated in the product documentation.

Compliance verification

The applicant shall declare compliance with the requirements in Annex 1 to the Contract and submit the corresponding pages of the product documentation or the EU energy efficiency label as Annex 6 to the Contract, in which the sound power level in cooling and, where relevant, heating operation is documented for both indoors and outdoors. In addition, the applicant shall submit a test report from a testing institution accredited according to DIN EN ISO/IEC 17025 as Annex 4, which demonstrates the calculation of the sound power level in accordance with the stated measurement guidelines in the EU regulation for air conditioners. Test reports completed by the applicant are recognised as being of an equivalent standard when the testing laboratory used for the measurements is accredited by an independent body as an SMT laboratory (supervised manufacturer testing laboratory).

It is possible to provide compliance verification based on product families ("Basic Model Groups") according to the Eurovent Certification[96].

3.5 Material requirements

3.5.1 Exclusion of hazardous substances

The EU Directive 2011/65/EU[97] (ROHS Directive) must be complied with. This refers to the substances lead, mercury, hexavalent chromium (chromium VI), polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).

The exemptions in the Annex to EU Directive 2011/65/EU (ROHS Directive) are not valid for this environmental label.

Compliance verification

The applicant shall declare compliance with the requirement in Annex 1 to the Contract and submit a declaration of conformity with the ROHS Directive as Annex 5.

3.5.2 Plastics used in the housing and housing parts

The plastics used in the housing and housing parts may not contain as constituent parts any substances classified as:

- carcinogenic in categories 1A or 1B according to Table 3.1 of Annex VI to EC Regulation 1272/2008[98]

[96] According to the Eurovent certification, product families ("Basic Model Groups" or BMG) are defined by units which are essentially the same in terms of their cooling and heating performance (+/-10%) and function (cooling or heating) and which are the same or comparable in terms of their basic components, specifically fans, heat exchangers, compressors and motors, according to EUROVENT (2015) Operational Manual for the Certification of Air Conditioners, http://www.eurovent-certification.com/fic_bdd/en/1435237711_OM-1-2015_AC.pdf (accessed on: 18.05.2016).

[97] Directive 2011/65/EC of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment

[98] Regulation (EC) No. 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, as well as amending Regulation (EC) No 1907/2006, Annex VI on harmonized classification and labelling of hazardous substances, Part 3: Harmonized classification and labelling, Tables, Table 3.2, – List of harmonized classification and labelling of dangerous substances from Annex I to Directive 67/548/EEC, short: GHS Regulation http://www.reach-info.de/ghs_verordnung.htm, each as amended.
The GHS Regulation (Global Harmonization System) that came into force on 20 January 2009, replaces the old Directives 67/548/EEC and 1999/45/EC. According to the said regulation, substances are classified, labelled and packed until 1 December 2010 according to Directive 67/548/EEC (Dangerous Substances Directive) while mixtures are classified, labelled and packed until 1 June 2015 according to Directive 1999/45/EC (Dangerous Preparations Directive). Notwithstanding this, the classification, labelling and packaging of substances and preparations may be performed according to the provisions of the GHS Regulation already before 1 December 2010 or 1 June 2015, respec-

- mutagenic in categories 1A or 1B according to Table 3.1 of Annex VI to EC Regulation 1272/2008
- reprotoxic in categories 1A and 1B according to Table 3.1 of Annex VI to EC Regulation 1272/2008
- particularly alarming for other reasons according to the criteria of Annex XIII to the REACH Regulation, insofar as they are included in the List (so-called "list of candidates"[99]) set up in accordance with REACH, Article 59, Paragraph 1.

Halogenated polymers shall not be permitted. Neither may halogenated organic compounds be added as flame retardants.

The following shall be exempt from this rule:

process-related, technically unavoidable impurities

fluoroorganic additives (e.g. anti-dripping agents) used to improve the physical properties of plastics, provided that they do not exceed a proportion of 0.5 percent by mass

plastic parts with a mass of less than or equal to 25 g

Compliance verification:

The applicant shall declare compliance with the requirements in Annex 1 to the Contract and submit a written declaration from the plastics manufacturer or guarantee the provision of these documents to RAL gGmbH. The declaration shall confirm that the excluded substances have not been added to the plastics and provide a chemical description of the flame-retardant materials used including the CAS number and its rating (H Phrases)(Annex P-M to the Contract). When first applying for the Blue Angel eco-label, the submitted declaration must not be older than 6 months. If one applicant submits additional applications for the labelling of products that contain the same plastics, the submitted declarations may be presented unchanged during the term of the Basic Award Criteria. Notwithstanding this, RAL shall be entitled to ask for an updated ver-

tively. In such cases, the provisions of the Dangerous Substances Directive or Dangerous Preparations Directive shall not be applicable.

[99] The version of the list of candidates at the time of application is valid (new applications). Link to the list of candidates of Regulation (EC) No. 1907/2006 concerning the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH): http://echa.europa.eu/web/guest/candidate-list-table

sion of the declarations if the Federal Environmental Agency (Umweltbundesamt) finds that product-relevant substances have been added to the list of candidates.

3.6 Environmentally friendly product design

Unless there are compelling technical reasons to the contrary, the following principles for the recyclable design of technical products must be observed and declared in writing:

The avoidance of non-detachable material connections between different materials

The avoidance of composite materials

Components that are easy to dismantle, also for the purpose of repair

Reduction in the diversity of the materials used

In addition, the manufacturer must provide a written declaration of compliance with the following requirements when applying for the environmental label:

Product components made of plastic with a weight of more than 25 g must be labelled with an abbreviated term in accordance with DIN EN ISO 1043-116 or DIN ISO 162917 (rubber) or DIN ISO 207618 (chemical fibres).

Compliance verification

The applicant shall declare compliance with the requirements in Annex 1 to the Contract and submit a list of product components made of plastic with a weight of more than 25 g together with the associated information in accordance with Annex P-L to the Contract.

3.7 Sales/Distribution

The air conditioners may only be installed and serviced by qualified specialist companies in accordance with Article 6 of the “Ordinance on climate protection against changes caused by release of certain fluorinated greenhouse gases” (Chemicals Climate Protection Ordinance – ChemKlimaschutzV). The installation must be carried out by a certified air conditioning and refrigeration technician in accordance with Category I of Regulation (EC) No. 303/2008[100] or in accordance with the Commission Implementing Regulation (EU) 2015/2067[101].

[100] Commission Regulation (EC) No. 303/2008 of 2 April 2008 establishing, pursuant to Regulation (EC) No 842/2006 of the European Parliament and of the Council, minimum requirements and the conditions for mutual

Compliance verification

The applicant shall declare in Annex 1 to the Contract that the device is only delivered to certified companies in accordance with Article 6 of ChemKlimaschutzV.

3.8 Services

The applicant themselves or a contractually affiliated service partner must offer services that enable the environmentally friendly planning and reliable and energy efficient operation of the air conditioners.

The following services must be offered:

- Professional planning, installation, maintenance and disposal of air conditioners by a specialist company in accordance with Paragraph 3.7.
- Provision of maintenance services at standard customer service times.
- Availability of equivalent spare parts for the repair of the air conditioners for at least 10 years after the devices are launched on the market.

Compliance verification

The applicant shall declare compliance with the requirements in Annex 1 to the Contract.

3.9 Product documentation

3.9.1 Operating instructions

The operating instructions are designed for the user of the air conditioner and must contain clear and understandable statements on the environmentally friendly operation of the device. The operating instructions must contain at least the following information:

---

recognition for the certification of companies and personnel as regards stationary refrigeration, air conditioning and heat pump equipment containing certain fluorinated greenhouse gases

[101] Commission Implementing Regulation (EU) 2015/2067 of 17 November 2015 establishing, pursuant to Regulation (EU) No 517/2014 of the European Parliament and of the Council, minimum requirements and the conditions for mutual recognition for the certification of natural persons as regards stationary refrigeration, air conditioning and heat pump equipment, and refrigeration units of refrigerated trucks and trailers, containing fluorinated greenhouse gases and for the certification of companies as regards stationary refrigeration, air conditioning and heat pump equipment, containing fluorinated greenhouse gases

- Information on the energy saving operation of the air conditioner, such as via the temperature settings, the avoidance of heat sources in the room and avoiding open windows or doors
- All product specific information in accordance with Regulation (EU) No. 626/2011, Annex IV.
- Information on the refrigerant used (see Paragraph 3.2) and, where necessary, special information about codes of conduct in the event of leakages, as well as the required maintenance cycles.
- Information that the air filters should be cleaned regularly and a description of the process for manual or automatic cleaning of the air filters (see Paragraph **Fehler! Verweisquelle konnte nicht gefunden werden.**)
- Information that the heat exchanger in the outdoor unit (condenser) should be regularly cleaned by trained specialists
- Information that the installation, annual service, maintenance and disposal of the device should only be carried out by a specialist company in accordance with Article 6 of the Chemicals Climate Protection Ordinance (ChemKlimaSchutzV) (see Paragraph **Fehler! Verweisquelle konnte nicht gefunden werden.**)

In addition, the operating instructions must be published on a freely accessible website that is easy to reach via the website of the manufacturer or supplier.

Compliance verification

The applicant shall declare compliance with the requirement in Annex 1 to the Contract, state the website where the operating instructions can be accessed and submit the corresponding pages of the operating instructions on which the relevant information is provided as Annex 6.

3.9.2 Installation and Service Manual

The Installation and Service Manual is designed for qualified specialists and must contain clear and unambiguous statements for the correct installation, servicing, maintenance and disposal of the air conditioners by qualified specialists. It must be clearly labelled as a guide “for qualified specialists”. The Installation and Service Manual must contain at least the following information:

Information before and during the installation:

- o The suitability of rooms for the installation of air conditioners (e.g. taking into account existing electrical installations)
- o Information on the required room sizes depending on the filling volume of the refrigerant in the air conditioner, taking into account the installation height of the indoor unit
- o Information on checking the completeness of all components and accessories for the air conditioner

- Information on professional leak testing during routine services or repairs
- Information on ensuring that measures to prevent a potentially explosive atmosphere remain effective after maintenance work
- Information on the professional removal/disposal of the refrigerant when dismantling the air conditioner

Information on work safety (avoidance of explosive atmospheres)

Information on the required tools

Information on relevant standards and norms (e.g. DIN EN 378, DIN EN 13313),

Information on the qualification of specialist personnel for the handling of flammable refrigerants

Information on reducing energy and refrigerant losses

Instructions for the professional cleaning of the device, filter and heat exchanger.

Compliance verification

The applicant shall declare compliance with the requirement in Annex 1 to the Contract and submit the corresponding pages of the Installation and Service Manual on which the relevant information is provided as Annex 7.

3.10 Outlook

The following requirements will be examined or, if necessary, supplemented in future revisions of these Basic Award Criteria:

Information on energy efficiency during operation (e.g. a meter for the volume of electricity and heat, data on the compressor speed).

Reduction in the requirements for noise emissions for outdoor units to a sound power level of less than 60 dB(A).

Interfaces for connecting the devices to home automation systems.

4 Applicants and parties involved

4.1 Manufacturers or distributors of products according to Paragraph 2 shall be eligible for application.

4.2 Parties involved in the award process are:

RAL gGmbH to award the Blue Angel ecolabel,
the federal state being home to the applicant's production site,
Umweltbundesamt (German Federal Environmental Agency) which after the signing of the contract receives all data and documents submitted in application for the Blue Angel in order to be able to further develop the Basic Award Criteria.

5 Use of the Environmental Label

5.1 The terms governing the use of the Environmental Label by the applicant are stipulated by a Contract on the Use of the Environmental Label to be concluded with RAL gGmbH.

5.2 Within the scope of such contract, the applicant undertakes to comply with the requirements under Paragraph **Fehler! Verweisquelle konnte nicht gefunden werden.** while using the environmental label.

5.3 Contracts on the Use of the Environmental Label are concluded to fix the terms for the certification of products under Paragraph **Fehler! Verweisquelle konnte nicht gefunden werden.**. Such contracts shall run until 31 December 2020.

They shall be extended by periods of one year each, unless terminated in writing by 31 March 2020 or 31 March of the respective year of extension.

After the expiry of the contract, the Environmental Label may neither be used for labelling nor for advertising purposes. This regulation shall not affect products being still in the market.

5.4 The applicant (manufacturer) shall be entitled to apply to RAL gGmbH for an extension of the right to use the ecolabel on the product entitled to the label if it is to be marketed under another brand/trade name and/or other marketing organizations.

5.5 The Contract on the Use of the Environmental Label shall specify:

5.5.1 Applicant (manufacturer/distributor)

5.5.2 Brand / trade name, product designation

5.5.3 Distributor (label user), i.e. the marketing organization under Paragraph **Fehler! Verweisquelle konnte nicht gefunden werden.**.4.

CONTRACT

No.

on the Award of the Environmental Label

RAL gGmbH as the label-awarding agency and the firm of

(Applicant/Distributor)

as the applicant conclude the following
Contract on the Use of the Environmental Label:

S P E C I M E N

1. Under the following conditions the applicant shall be entitled to use the Environmental Label for the labelling of the product / product group / project: **"Stationary air conditioners"** for

   "(Brand/Trade Name)"

   This shall not include the right to use the Environmental Label as part of a brand. Unless otherwise agreed, the Environmental Label shall only be used in the above given shape and colour and shall be marked at the bottom "Jury Umweltzeichen" (Environmental Label Jury). The entire inner surrounding text shall always be identical as regards font size, form, thickness and colour and it shall be easy to read.
2. The Environmental Label according to Paragraph 1 may only be used for the above-mentioned product / product group / project.
3. If the Environmental Label is used for advertising purposes or other applicant activities, the applicant shall make sure that it is exclusively used in connection with the above-named product / product group / project for which the use of the Environmental Label has been granted and settled under this contract. The label holder shall be solely responsible for the way the label is used, above all, in advertising.
4. During the entire period of label use, the product / product group / project to be labelled shall comply with all requirements and conditions for the use of the label as specified in the "Basic Criteria for Award of the Environmental Label RAL-UZ **204**", as amended. This shall also apply to the reproduction of the Environmental Label (including surrounding text). Claims for damages against RAL gGmbH, especially on the grounds of third party objections to applicant's use of the label and the accompanying advertising shall be ruled out.
5. If the "Basic Criteria for Award of the Environmental Label" provide for checks by third parties, the applicant shall bear the costs accruing in connection therewith.
6. Should the applicant himself or third parties find out that the applicant does not comply with the conditions as stipulated in Paragraphs 2-5, the applicant shall be liable to inform RAL gGmbH and stop the use of the Environmental Label until the conditions are complied with again. Should the applicant be incapable of restoring the state required for the use of the label immediately or should the applicant seriously offend against this contract, RAL gGmbH may, if necessary, withdraw the Environmental Label and prohibit the applicant from using the label any longer. Claims for damages against RAL gGmbH because of the withdrawal of the label shall be ruled out.
7. The Contract on the Use of the Environmental Label may be terminated for good reason.
   Examples of good reasons are:
   - unpaid contributions
   - substantiated risk of injury and death.

   In such case, the applicant's continued use of the Environmental Label shall be prohibited. The applicant shall not be entitled to bring a claim for damages against RAL gGmbH (see above: Paragraph 6, Sentence 3).
8. The applicant undertakes to pay RAL gGmbH an amount according to the "Entgeltordnung für das Umweltzeichen" (Schedule of Fees for the Environmental Label), as amended, for the period of use.
9. According to the "Basic Criteria for Award of the Environmental Label RAL-UZ **204**" this contract will run until 31 December **2020**. They shall be extended by periods of one year each, unless terminated in writing by 31 March **2020** or March 31 of the respective year of extension. After the expiry of the contract, the Environmental Label may neither be used for labelling nor for advertising purposes. This regulation shall not affect products being still in the market.
10. Products / projects marked with the Environmental Label and the advertising for these products / projects may reach the consumer only when naming the company of the

    (Applicant/Distributor)

Sankt Augustin, this … . day of ………………..20..

Location, Date

RAL gGmbH
Management

(Signature of authorized person
and company stamp)

10 References

Bright Management Consulting 2013

Bright Management Consulting Co., Ltd. (2013): Data collection support for establishing an inventory of consumption and emission of F-gases (CFC, HCFC, HFCs, PFCs and SF6) in Thailand

Christoph 2002 — Christoph, E. (2002): Bilanzierung und Biomonitoring von Trifluoracetat und anderen Halogenacetaten. Dissertation zur Erlangung des Doktorgrades der Fakultät Biologie, Chemie und Geowissenschaftender Universität Bayreuth.

De Kleine 2009 — De Kleine, Robert (2009): Life cycle optimization of residential air conditioner replacement. University of michigan. Online verfügbar unter http://css.snre.umich.edu.

Deubzer 2011 — Deubzer, Otmar (2011): E-waste Management in Germany. Hg. v. GIZ. Online verfügbar unter http://isp.unu.edu/publications/scycle/files/ewaste-management-in-germany.pdf (Zugriff am 22. April 2016).

EC Enterprise and Industry 2013

European Commission Enterprise and Industry (2013): Critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials

Ellis et al. 2001 — Ellis, D.A.; Hanson, M.L.; Sibley, P.K.; Shahid, T.; Fineberg, N.A.; Solomon, K.R.; Muir, D.C.G.; Mabury, S.A. (2001): The fate and persistence of trifluoroacetic and chloroacetic acids in pond waters. Chemosphere 42 (2001), 309-318.

EUROSTAT 2015 — European Commission – EUROSTAT: Waste Electrical and Electronic Equipment (WEEE).2015. Online available at http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do.

FGK Status report 26 — Fachverband Gebäude-Klima e.V. (2014): Informationsschrift "Qualitätssiegel Raumklimageräte", Download: www.qualitaetssiegel-raumklimageraete.de/

GIZ Proklima 2013 — Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (2013): NAMAs in the refrigeration, air conditioning and foam sectors. A technical handbook. On behalf of German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety.

GIZ Proklima 2014 — Heubes, J.; Papst, I.; Gloël, J. (Deutsche Gesellschaft für Internationale Zusammenarbeit – GIZ GmbH (2014): Management and destruction of existing ozone depleting substances banks.On behalf of German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety.

Godrej 2013 — Godrej Appliances (2013): Development and Handling of Hydrocarbon Air-conditioners – The Godrej Experience; http://www.hydrocarbons21.com/knowledge/papersView/1434.

Greenpeace 2012 — Greenpeace (2012): Position Paper, HFOs: the new generation of F-Gases, http://conf.montreal-protocol.org/meeting/oewg/oewg-32/ngo-publications/NGO%20Publications/Greenpeace%20Position%20Paper%20on%20HFOs%20July%202012.pdf

Grießhammer et al. 2007

Grießhammer, R.; Buchert, M.; Gensch, C.-O.; Hochfeld, C.; Manhart, A.; Rüdenauer, I.: in collaboration with Reisch, L. (2007): PROSA – Product Sustainability Assessment. Guideline. Oeko-Institut e.V. in cooperation with Copenhagen Business School (CBS). Sponsored by the German Federal Ministry of Education and Research (BMBF), Berlin.

Groeger et al. 2013 Gröger, J.; Quack, D.; Gattermann, M.; Grießhammer, R. (2013): Top 100 – Umweltzeichen für klimarelevante Produkte. Endbericht [Top 100 – Ecolabel for climate-relevant products. Final report]. Sponsored by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Berlin / Project Management Jülich.

Haier 2013 Haier Group (2013): R-290 R&D Report, Haier Air Conditioners. http://www.hydrocarbons21.com/knowledge/papersView/1435.

HEAT 2015 Personal communication between Oeko-Institut and Heat GmbH.

UBA 2014 Heubes, J.; Papst, I.; König, H.; Usinger, J.; Gschrey, B.; Kimmel, T.; Schwarz, W. (HEAT GmbH & Öko-Recherche) (2013); Umweltbundesamt – UBA (Ed.): Kohlenwasserstoffe sicher als Kältemittel einsetzen - Entwicklung einer Strategie zum vermehrten Einsatz von Kohlenwasserstoff-Kältemitteln als Beitrag zum deutschen Klimaschutzziel unter Berücksichtigung des Energieziels 2050“. Im Auftrag des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit, FKZ 03KSE046.

Honeywell 2014 Honeywell International Inc. (2014): SAFETY DATA SHEET Solstice® yf Refrigerant (R-1234yf) 000000011078. Version 2.3. Revision date 06/17/2014; Print Date 07/30/2015

Key et al. 1977 Key, B. D.; Howell, R. D.; Criddle, C. S. (1997):
Critical Review Fluorinated Organics in the Biosphere, 31(9), 2445–2454.

LBNL 2015 Shah, N.; Wei, M.; Letschert, V.; Phadke, A. (2015): Ernest Orlando Lawrence Berkeley National Laboratory (Ed.): Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning.

Rajadhyasha et al. 2014

Rajadhyasha, D.; Wadia, B.J.; Acharekar, A.; Colbourne, D. (2014): The first 60,000 HC-290 Split Air Conditioners in India, Publication for the 11th IIR Gustav Lorentzen Conference on Natural Refrigerants, Hangzhou, China, 2014

Rivière 2008 Rivière, P. (2008): Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation). Final report of Task 5.

SEAD 2013 Shah, N., Phadke, A., Waide, P. (2013); Super-efficient Appliance and Equipment Deployment (SEAD) (Ed.): Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners.

UNEP 2013 United Nations Environment Programme – UNEP (2013): Discussion paper on minimizing adverse climate impact of HCFC phase-out in the refrigeration servicing sector (decision 68/11), UNEP/OzL.Pro/ExCom/71/56

Zacharias et al. 2014 Zacharias, S.; Koppe, C.; Mücke, H.-G. (2014): Climate Change Effects on Heat Waves and Future Heat Wave-Associated IHD Mortality in Germany. Climate Vol. 3, 100–117. doi:10.3390/cli3010100

Zhang et al. 2013 Zhang, W.; Yang, Z.; Li, J.; Ren, C.-X.; Lv, D.; Wang, J.; Zhang, X.; Wu, W. (2013) Research on the flammability hazards of an air conditioner using refrigerant R-290. International Journal of Refrigeration, Vol 36(5), 1483-1494.

11 Annex

I: Overview of standards and EU-Directives

Table 46: Relevant European Directives and harmonised standards and ISO standards for single-split air conditioners

Directive (DIR)	Year	Title	Relevant harmonised standards
DIR 2006/95/EC	2006	Low Voltage Directive (LVD) in Deutschland umgesetzt als: 1.Verordnung zum Produktsicherheitsgesetz	DIN EN 60335-2-40
DIR 97/23/EG	1997	European Pressure Equipment Directive (PED) (Druckgeräterichtlinie) In Deutschland umgesetzt durch die 14. Verordnung zum Produktsicherheitsgesetz (Druckgeräteverordnung)	DIN EN 378 DIN EN 14276
ProdSG	2001	Produktsicherheitsgesetz, ersetzt seit 2001 das GPSG (Geräte- und Produktsicherheitsgesetz)	
DIR 2006/42/EG	2006	Maschinenrichtlinie: einheitliches Schutzniveau zur Unfallverhütung für Maschinen (Directive 2006/42/EC on machinery) in Deutschland umgesetzt als: 9. Verordnung zum Produktsicherheitsgesetz (Maschinenverordnung)	DIN EN 378
DIR 94/9/EG	1994	ATEX Produktrichtlinie (europäische Richtlinie, harmonisiert nationale Richtlinien) (inoffizieller Name: ATEX 95) in Deutschland umgesetzt als: 11. Verordnung zum Produktsicherheitsgesetz (Explosionsschutzverordnung)	EN 60079-0 EN 60079-15 EN 60079-20-1
DIR 1999/92/EG	1999	Richtlinie über Mindestvorschriften zur Verbesserung des Gesundheitsschutzes und der Sicherheit der Arbeitnehmer, die durch explosionsfähige Atmosphären gefährdet werden können (ATEX-Betriebsrichtlinie)	
ISO 5149	1993, Draft 2014	Mechanische Kälteanlagen zum Kühlen und Heizen	
ISO 817	2014	Refrigerants -- Designation and safety classification	

Table 47: Relevant German standards for single-split air conditioners

Standard	Year	Titel	Special require-ments*
DIN EN 378	2012	Kälteanlagen und Wärmepumpen – Sicherheitstechnische und umweltrelevante Anforderungen	X
		Teil 1: Grundlegende Anforderungen, Begriffe, Klassifikationen und Auswahlkriterien	
		Teil 2: Konstruktion, Herstellung, Prüfung, Kennzeichnung und Dokumentation	
		Teil 3: Aufstellungsort und Schutz von Personen	
		Teil 4: Betrieb, Instandhaltung, Instandsetzung und Rückgewinnung	
DIN EN 1127-1	2011	Explosionsfähige Atmosphären - Explosionsschutz – Teil 1: Grundlagen und Methodik	X
DIN EN 1736	2009	Kälteanlagen und Wärmepumpen – Flexible Rohrleitungsteile, Schwingungsabsorber, Kompensatoren und Nichtmetall-Schläuche – Anforderungen, Konstruktion und Einbau	
DIN EN ISO 4126	2002 Entwurf 2010	Sicherheitseinrichtungen gegen unzulässigen Überdruck Teile 1-7	
DIN EN ISO 9001	2008	Qualitätsmanagementsysteme – Anforderungen	
DIN EN ISO 12100	2011	Sicherheit von Maschinen – Allgemeine Gestaltungsleitsätze – Risikobeurteilung und Risikominderung	X
DIN EN 12178	2004	Kälteanlagen und Wärmepumpen – Flüssigkeitsstandanzeiger – Anforderungen, Prüfung und Kennzeichnung	
DIN EN 12263	1999	Kälteanlagen und Wärmepumpen – Sicherheitsschalteinrichtungen zur Druckbegrenzung – Anforderungen und Prüfungen	
DIN EN 12284	2003	Kälteanlagen und Wärmepumpen – Ventile – Anforderungen, Prüfung und Kennzeichnung	
DIN EN 12693	2008	Kälteanlagen und Wärmepumpen – Sicherheitstechnische und umweltrelevante Anforderungen – Verdrängerverdichter für Kältemittel	
DIN EN 13136	2005, Entwurf 2011	Kälteanlagen und Wärmepumpen – Druckentlastungseinrichtungen und zugehörige Leitungen – Berechnungsverfahren	
DIN EN 13463-1, -5, -6	2009	Nicht-elektrische Geräte für den Einsatz in explosionsgefährdeten Bereichen	X
EN 13980	2003	Potentially explosive atmospheres – Application of quality systems	X

Standard	Year	Titel	Special require-ments*
DIN EN 13313	2011	Kälteanlagen und Wärmepumpen – Sachkunde von Personal	
DIN EN 14276-1, -2	2011	Druckgeräte für Kälteanlagen und Wärmepumpen	X
DIN EN 14986	2007	Konstruktion von Ventilatoren für den Einsatz in explosionsgefährdeten Bereichen	X
DIN EN 15198	2007	Methodik zur Risikobewertung für nicht-elektrische Geräte und Komponenten zur Verwendung in explosionsgefährdeten Bereichen	X
DIN EN 15233	2007	Methodik zur Bewertung der funktionalen Sicherheit von Schutzsystemen für explosionsgefährdete Bereiche	X
EN 15834	2009	Standard on qualification of tightness of components and joints	
DIN EN 50110	2004	Betrieb von elektrischen Anlagen	
		Teil 1: Allgemeine Anforderungen (Entwurf 2012)	
		Teil 2: Nationale Anhänge	
DIN EN 50402	2009	Elektrische Geräte für die Detektion und Messung von brennbaren oder toxischen Gasen und Dämpfen oder Sauerstoff – Anforderungen an die funktionale Sicherheit von ortsfesten Gaswarnsystemen	X
DIN EN 60079-0	2013	Teil 0: Betriebsmittel – Allgemeine Anforderungen	X
DIN EN 60079-10-1	2009 Entwurf 2011	Teil 10-1: Einteilung der Bereiche – Gasexplosionsgefährdete Bereiche	X
DIN EN 60079-14	2012	Teil 14: Projektierung, Auswahl und Errichtung elektrischer Anlagen	X
DIN EN 60079-15	2011	Teil 15: Geräteschutz durch Zündschutzart „n“	X
DIN EN 60079-17	2008, Entwurf 2011	Teil 17: Prüfung und Instandhaltung elektrischer Anlagen	X
DIN EN 60079-19	2011	Teil 19: Gerätereparatur, Überholung und Regenerierung	X
DIN EN 60079-20-1	2010	Teil 20-1: Stoffliche Eigenschaften zur Klassifizierung von Gasen und Dämpfen – Prüfmethoden und Daten	X
DIN EN 60204-1	2010	Sicherheit von Maschinen – Elektrische Ausrüstung von Maschinen – Teil 1: Allgemeine Anforderungen	
DIN EN 60335-1	2012 Entwurf 2013	Sicherheit elektrischer Geräte für den Hausgebrauch und ähnliche Zwecke – Teil 1: Allgemeine Anforderungen	

Standard	Year	Titel	Special require-ments*
DIN EN 60335-2-34	2009 Entwurf 2011	Teil 2-34: Besondere Anforderungen für Motorverdichter	
DIN EN 60335-2-40	2010 Entwurf 2012	Teil 2-40: Besondere Anforderungen für elektrisch betriebene Wärmepumpen, Klimageräte und Raumluft-Entfeuchter	X
DIN EN 60812	2006	Analysetechniken für die Funktionsfähigkeit von Systemen – Verfahren für die Fehlzustandsart- und -auswirkungsanalyse (FMEA)	X
DIN EN 61160	2006	Entwicklungsbewertung	
IEC 61882	2001	Gefährdungs- und Betreibbarkeitsuntersuchung (HAZOP) – Leitfaden	X
DIN EN 62502	2011	Verfahren zur Analyse der Zuverlässigkeit – Ereignisbaum-analyse	X
DIN EN ISO / IEC 17020	2012	Konformitätsbewertung – Anforderungen an den Betrieb verschiedener Typen von Stellen, die Inspektionen durchführen	
DIN EN ISO / IEC 17024	2012	Konformitätsbewertung – Allgemeine Anforderungen an Stellen, die Personen zertifizieren	
DIN EN ISO / IEC 17025	2005	Allgemeine Anforderungen an die Kompetenz von Prüf- und Kalibrierlaboratorien	

* Special requirements for flammable refrigerants or explosive atmospheres

Figure 31: Selected standards for the implementation of Commission Regulation (EU) No 206/2012 and Regulation (EU) No 626/2011

Measured parameter	Organisa-tion	Reference	Title
Test methods for SEER and SCOP	CEN	PrEN 14825:2011, Chapter 8 and 9	Air conditioners, liquid chilling packages and heat pumps, with electrical compressors, for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance
Standby power consumption	CEN	EN 62301:2005	Household Electrical Appliances: Measurement of standby power
Sound power level	CEN	EN 12102:2008	Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling - Measurement of airborne noise - Determination of the sound power
Energy efficiency	IEC	IEC 60879: 1986	Performance and construction of electric circu-

		(corr. 1992)	lating fans and regulators
Sound power level	EN	EN 60704-2-7:1997	Household and similar electrical appliances - Test code for the determination of airborne acoustical noise - Part 2: Particular requirements for fans

II: Analysis of charge size and energy efficiency

Relationship between charge size and efficiency considering charge size limits of the product standard EN 60335-2-40

Data basis

The AC product data were taken from the Eurovent database (http://www.eurovent-certification.com/, received: June 2015), indicating: manufacturer, model, cooling and heating capacity, SEER/SCOP and others. Initial charge values were randomly taken (n=200) from product sheets, based on the product specifications, because this parameter is currently not included in the Eurovent database.

Assumptions

- Convert R-410A unit charge to R-290: a conservative reduction scenario by 50% was used; Convert R-32 unit charge to R-290: a conservative reduction scenario was used, to end up with 55% of the initial charge.
- It is feasible that charge size could be further reduced in actual units developed for R-290, but the construction of the listed units is not known so it is not possible to estimate the extent of further charge reduction
- Capacity assumed to be equal (through selection of appropriately sized compressor)
- Efficiency assumed not to change
- Heat load
    - Heat load varies according to climate, room usage, construction, etc.: For Northern Europe heat load may range from 50 – 100 W/m². For Southern Europe and tropical countries heat load may vary from 100 – 200 W/m²
    - Thus, we differentiate between 100 W/m² (temperate climate) and 200 W/m² heat load (tropical climate)

Charge size

Five alternative methods for determining maximum charge size are assessed. The first is from the existing standard and the others are based on proposals for alternative methods for determining charge size.

Method 1

Calculation using current formula within DIN EN 60335-2-40 for "wall" units, i.e., h = 1.8 m, which is the most dominant application.

Method 2

Calculation using current formula within DIN EN 60335-2-40 for "wall" units, but assuming acceptance of currently discussed amendments, which permits choice of installation height, so h = 2 m is chosen.

This modification is very likely to be implemented in DIN EN 60335-2-40 by the end of the year 2016.

Method 3

Calculation using currently discussed formula for systems with improved tightness, m_{max} = $0.5LFL \times h \times A$, where h = 2 m

Method 4

Calculation using currently discussed formula for systems with some minimum integral airflow, $mmax$ = $0.35LFL \times 2.2 \times A$

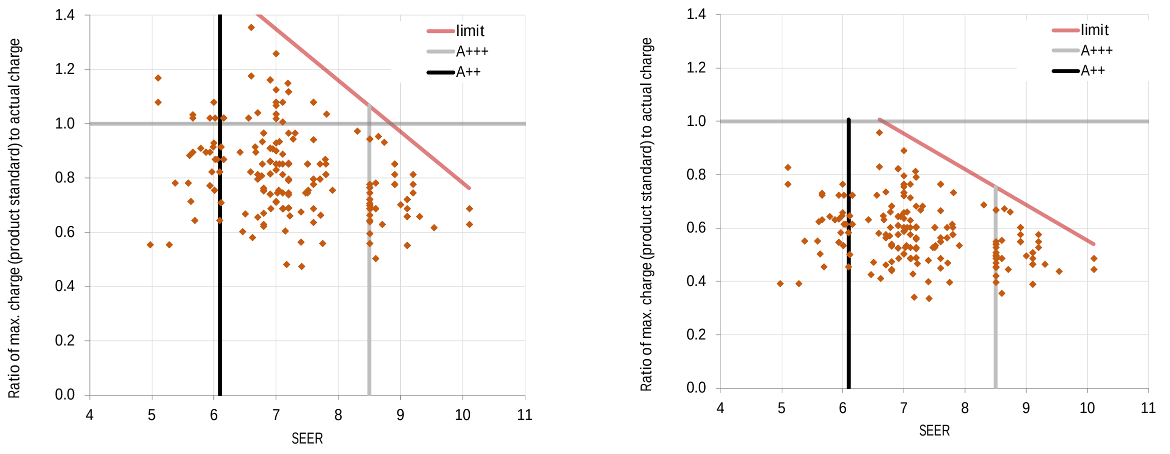
Method 5

Calculation using current formula within DIN EN 60335-2-40, but with shut-off valves to reduce the releasable charge, m_{max} = $2.5LFL^{1.25} \times h \times \sqrt{A}/(1 - \varphi_{ret})$, where the fraction of charge retained within the system φ_{ret} = 0.5 and h = 2 m

Please note: Assumptions as stated under method 3, 4 and 5 are currently discussed within the standard committees and can be found within proposals for a review of the product standard DIN EN 60335-2-40. There is a certain but not quantifiable chance that these methods will be adopted, but probably not within the next two years.

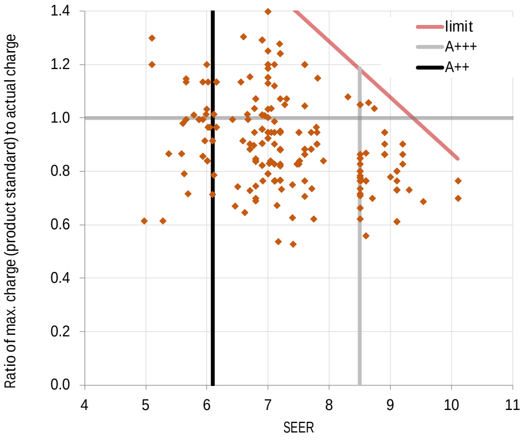
Results

Results are expressed as the ratio of maximum charge calculation (according the various methods) to unit charge. Values greater than 1 infer sufficient charge is allowed. If there is a triangle between the ratio = 1 line, the A+++ line and the "limit" line, it implies there are scope for using R-290 in units greater than A+++. If there is no triangle there is negligible possibility for using R-290 in A+++ or higher.

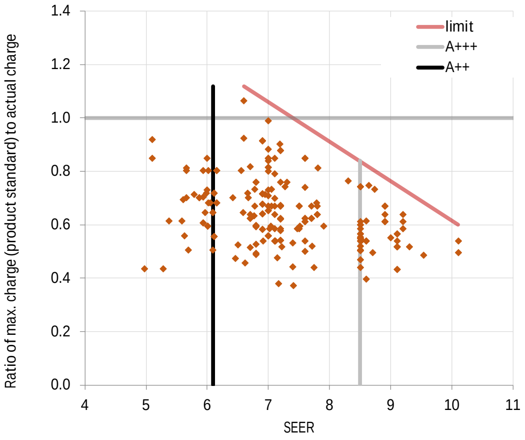


Method 1, Q = 100 W/m²

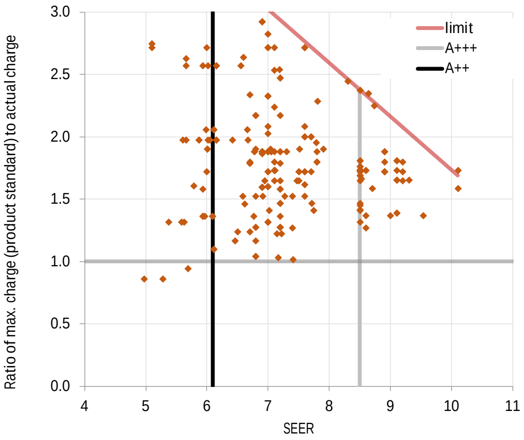
Method 1, Q = 200 W/m²



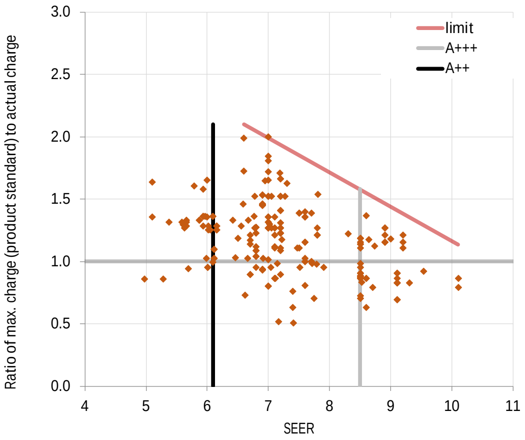
Method 2, Q = 100 W/m²



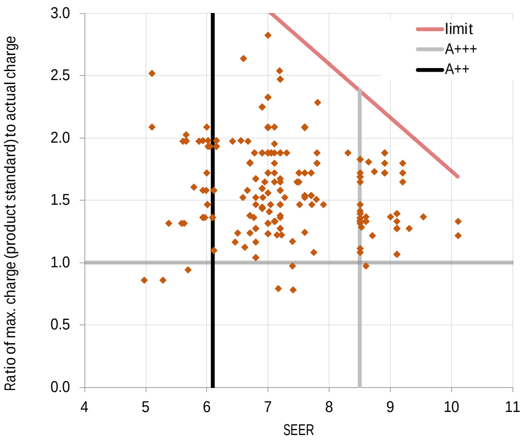
Method 2, Q = 200 W/m²



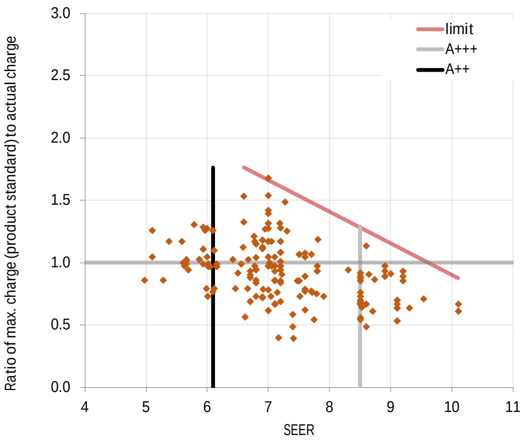
Method 3, Q = 100 W/m²



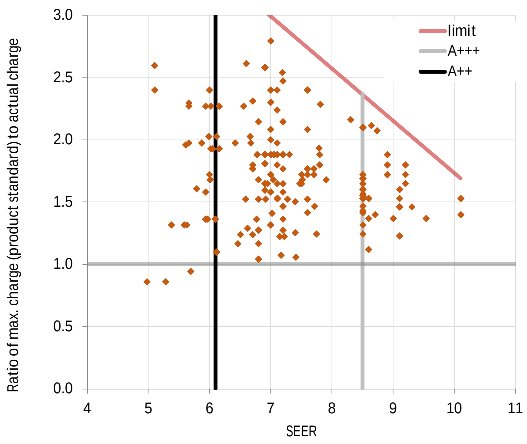
Method 3, Q = 200 W/m²



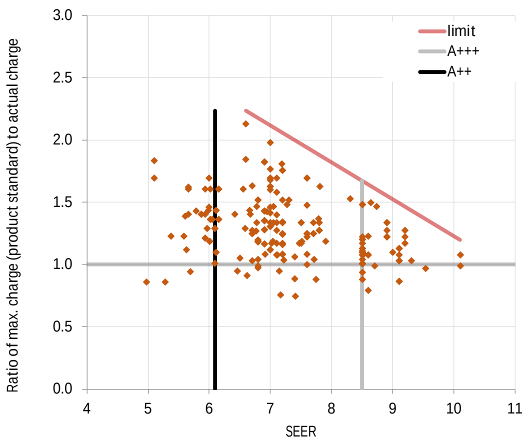
Method 4, Q = 100 W/m²



Method 4, Q = 200 W/m²



Method 5, Q = 100 W/m²



Method 5, Q = 200 W/m²

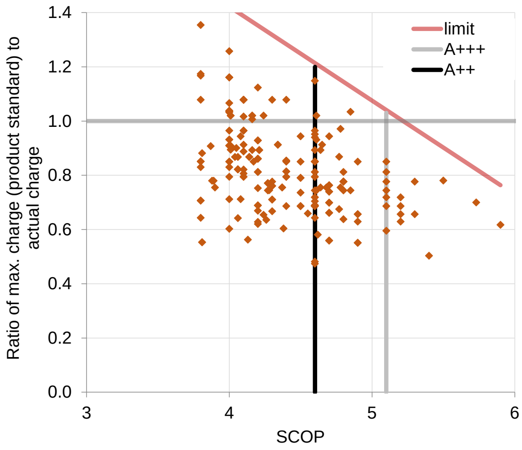
The conclusions of the results are summarized in Table 48, using traffic light colouring. Consequently, in temperate climates (100 W/m² heat load) the A+++ setting in combination with hydrocarbon refrigerant is difficult to realise and seems impossible in tropical countries. These circumstances might change in the future (method 3-5), with expected adaptations of the product standard. However, the authors do not expect the modifications to happen within the next two years.

Table 48: Evaluation scheme

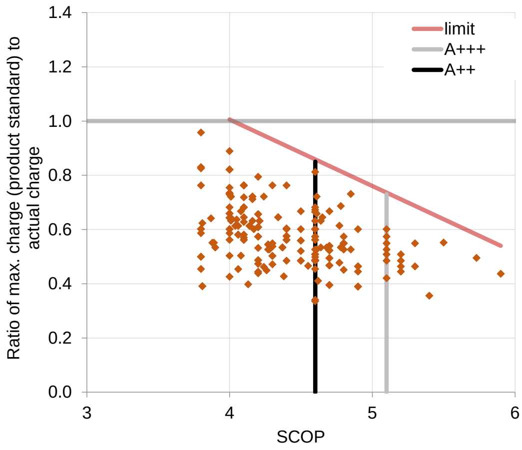
Q = 100 W/m²	Q = 200 W/m²
Method 1	Method 1
Method 2	Method 2
Method 3	Method 3
Method 4	Method 4
Method 5	Method 5

Qualitative evaluation (traffic light scheme) of setting the energy efficiency of single spilt AC to A+++ (Regulation (EU) No 626/2011) and the use of propane as refrigerant, considering the current implementation of the product standard DIN EN 60335-2-40 (method 1) including various adaptations (method 2-5). The heat load Q = 100 W/m² represents a temperate climate, whereby Q = 200 W/m² represents a tropical climate.

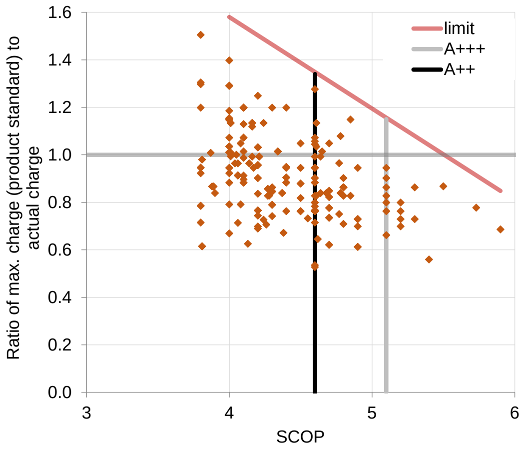
The same analysis was done for the SCOP values (figures below). The conclusions with regard to the various methods are the same as for SEER, however, the SCOP values are at a lower range. The median SCOP value is given with 4 (sample from Eurovent database), the lower bound of A++ is 4.6 and 5.1 for A+++.



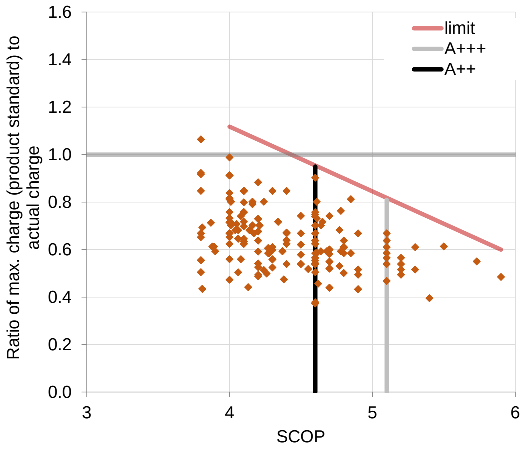
Method 1, Q = 100 W/m²



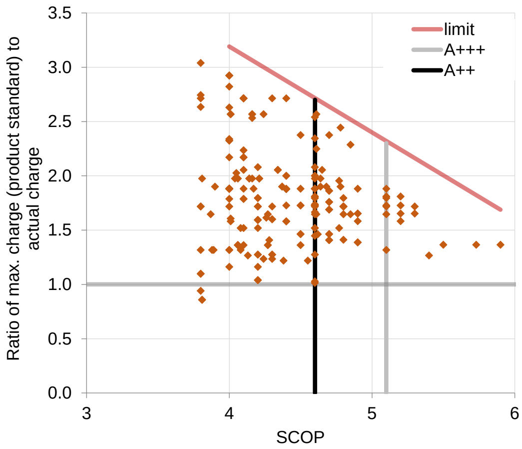
Method 1, Q = 200 W/m²



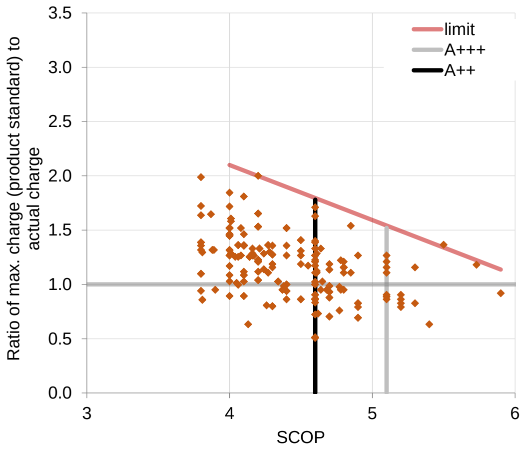
Method 2, Q = 100 W/m²



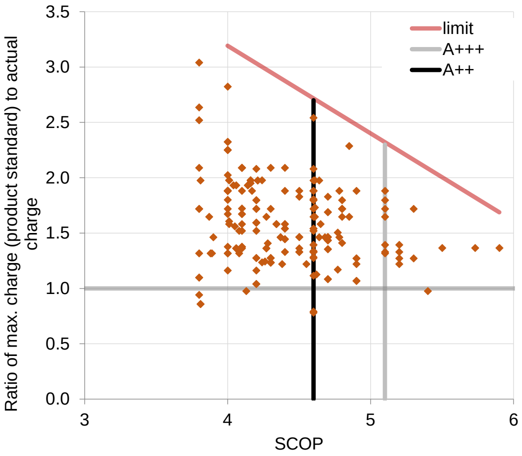
Method 2, Q = 200 W/m²



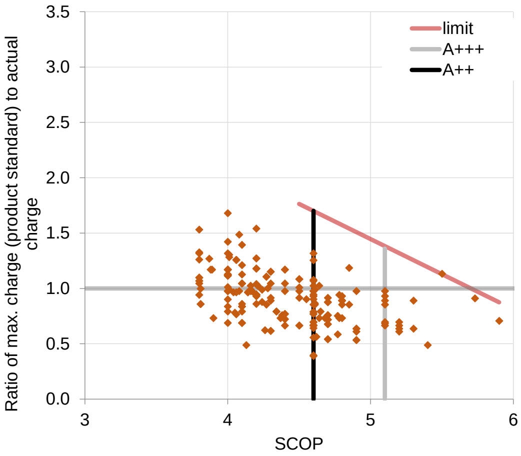
Method 3, Q = 100 W/m²



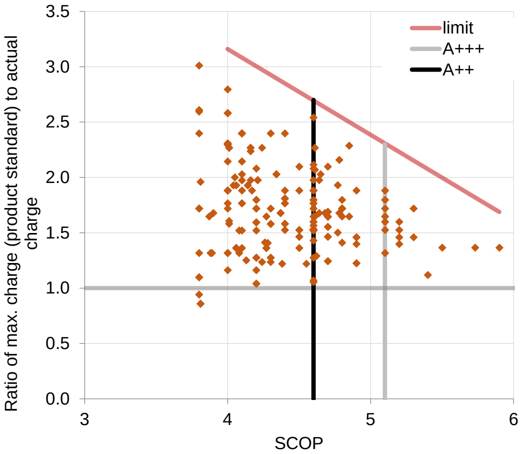
Method 3, Q = 200 W/m²



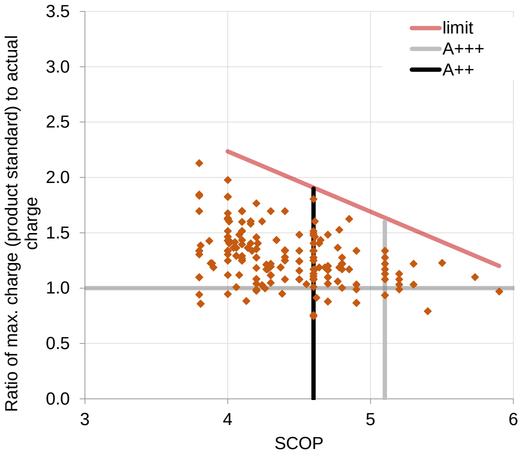
Method 4, Q = 100 W/m²



Method 4, Q = 200 W/m²



Method 5, Q = 100 W/m²



Method 5, Q = 200 W/m²