Technical Note on Quality and Performance Metrics of Cooling Products for East African Community (EAC) and Southern African Development Community (SADC)

Room Air Conditioners

A report prepared for the United for Efficiency supported regional harmonization of minimum energy performance standards (MEPS) and labels for air conditioners in the EAC and SADC regions.

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Executive Summary

Increasing population, incomes, and urbanization—as well as a warming climate—are driving up the global stock of cooling equipment such as air conditioners (ACs) and refrigerating appliances, particularly in emerging economies with hot climates, including African countries. Because cooling energy consumption is expected to increase substantially as the stock of cooling equipment rises, improving energy efficiency will be critical to reducing energy, life cycle cost, peak load, and emissions impacts, as well as increasing access to cooling.

In addition, the Montreal Protocol has evolved from focusing solely on ozone layer protection to addressing climate change mitigation as well, with the 2016 Kigali Amendment establishing a framework for reducing global hydrofluorocarbon (HFC) use. This shift presents an opportunity to link the HFC phasedown with the deployment of energy-efficient cooling equipment and thus provide benefits in terms of greenhouse gas reductions, technical and economic synergies, and reduced dumping of environmentally harmful products in developing countries.

The report, *Overview of the Market on Refrigerating Appliances and Room Air Conditioners in Eastern and Southern Africa*, [1] outlines the findings of the market assessment that can help policymakers facilitate an effective market transformation to promote energy-efficient and climate-friendly room ACs and residential refrigerators for countries in the East African Community (EAC) and Southern African Development Community (SADC).

This technical note particularly supports EAC and SADC's effort to establish and improve energy-efficiency standards for room ACs by providing an overview of global market and policy trends and technical recommendations in a harmonized way across the region. Primarily based on the market assessment [1] and the United for Efficiency (U4E) Model Regulation Guidelines for ACs [2], [3], several preliminary recommendations are made for further discussion amongst the EAC and SADC member countries:

1. **Establish a regionally harmonized energy-efficiency standard and compliance infrastructure**. Only 6 countries from EAC and SADC have minimum energy performance standards (MEPS) (3 mandatory and 3 voluntary) in place for room ACs, while cooling energy consumption is expected to increase substantially in the coming years. This policy action can help countries achieve the maximum efficiency that is technologically feasible and economically/environmentally justified and leverage decades of experience from energy-efficiency programs in other regions.
2. **Establish and harmonize energy-efficiency standards and labeling requirements, and test standards aligned with international standards and U4E Model Regulation Guidelines by developing an energy-efficiency roadmap for cooling equipment,** to capture cost and energy savings while minimizing environmental impacts, encouraging innovation and

realizing economies of scale in the industry. In EAC and SADC regions, it seems common to find mixed labels from countries of origin of the products, which are not directly comparable and confuse consumers.

3. **Implement energy-efficiency standards that consider low-GWP refrigerants along with improvement of safety standards.** Combining refrigerant transition with energy efficiency improvement double the emissions impact of either policy implemented in isolation and help lower costs. Rwanda's National Cooling Strategy established MEPS and energy labels for room ACs and refrigerating appliances with energy-efficiency requirements and refrigerant GWP limits based on U4E Model Regulation Guidelines.
4. **Establish an appropriate infrastructure for product certification and registration by harmonizing databases regionally and allow data sharing.** Product databases serve as initial gateways for registering compliant products with regulatory authorities. Development and administration of integrated product registration databases could prove burdensome if undertaken by individual jurisdictions and regulatory agencies. Harmonizing the efforts across jurisdictions in a region would reduce this burden.
5. **Establish an appropriate infrastructure for testing or verifying energy-efficiency performance** by exploring testing collaboration opportunities through mutual recognition agreements among governments, governments and test laboratories, and test laboratories in different regions, which mitigate the cost of testing laboratories and strengthen compliance schemes.
6. **Strengthen the compliance regime.** Nonexistent or inadequate energy-efficiency programs can allow countries to become dumping grounds for products that cannot be sold elsewhere, hindering control of harmful substances and promoting wasteful energy consumption. A regularized monitoring system for tracking compliance with the mandatory standard and energy information labeling programs would accelerate the replacement of less-efficient products, and facilitate the transformation of the regional market for energy-efficient products.
7. **Consider adopting a seasonal efficiency metric, e.g., the ISO cooling seasonal performance factor (CSPF) metric.** Many countries in other regions have already moved to, or are planning to, adopt the ISO 16358 standard for rating the performance of ACs. The Rwanda seasonal energy efficiency ratio (RSEER) is consistent with the ISO CSPF metric with Rwanda's climate profile applied. Adopting this widely used metric would improve room AC standards and labeling in EAC and SADC countries, while facilitating harmonization with international AC-efficiency efforts.
8. **Combine fixed-speed (non-inverter) and variable-speed (inverter) AC product categories under the same metric** so that consumers clearly differentiate between the two and benefit from the energy savings from variable-speed ACs.

9. **For determining the CSPF of fixed-speed units, reduce compliance costs by using only one set of test data at full-capacity operation at 35°C**, and use another set of data points at 29°C calculated by predetermined equations, which results in a linear relationship with EER, i.e., CSPF = 1.062 × EER with the ISO reference temperature bin hours.
10. **For variable-speed units, determine CSPF while reducing compliance costs by using two sets of test data at full- and half-capacity operation at 35°C** and another set of data points at 29°C calculated by predetermined equations, without considering a minimum-capacity operation.
11. **Consider using only a single reference set of temperature bin hours (e.g., the ISO 16358 temperature bin hours) for CSPF metrics** in all EAC and SADC countries to evaluate efficiency performance of ACs with energy-efficiency standards and labeling requirements. Using a single set of bin hours would reduce additional costs for manufacturers, regulatory complexity for government agencies, and confusion for consumers, compared with using multiple sets of bin hours for different climate zones.
12. **Consider additionally using the ISO CSPF metric based on country-specific bin hours of AC use for assessing and informing absolute impacts** (energy use, electricity cost, emissions, etc.). The ISO 16358 temperature bin hours could be used for efficiency standard purposes without impacting the relative order of efficiency ratings and reducing compliance costs. However, hours of AC use and estimates of total energy use in ACs may need to be adjusted to reflect each country context more accurately.
13. **Harmonize energy-efficiency standards and labels aligned with U4E Model Regulation Guidelines** to capture cost and energy savings while minimizing environmental impacts and encouraging innovation in the industry. The U4E Model Regulation Guidelines minimum efficiency requirements for room ACs are roughly aligned with the prospective 2022 MEPS for room ACs in China that accounts for about 70% of the global room AC production. Thus, economies that harmonize with the U4E Model Regulation Guidelines will likely benefit from the lower prices for efficient ACs from the resulting economies of scale.
14. **Update standards periodically** to mitigate risk of obsolete technology being deployed in markets without updated standards, as well as reflect benefits of commercially available and emerging technology.

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1. Context and background

Increasing population, incomes, and urbanization—as well as a warming climate—are driving up the global stock of cooling equipment such as air conditioners (ACs) and refrigerating appliances, particularly in emerging economies with hot climates, including African countries. Because cooling energy consumption is expected to increase substantially as the stock of cooling equipment rises, improving energy efficiency will be critical to reducing energy, life cycle cost, peak load, and emissions impacts, as well as increasing access to cooling.

In addition, the Montreal Protocol has evolved from focusing solely on ozone layer protection to addressing climate change mitigation as well, with the 2016 Kigali Amendment establishing a framework for reducing global hydrofluorocarbon (HFC) use. This shift presents an opportunity to link the HFC phasedown with the deployment of energy-efficient cooling equipment and thus provide benefits in terms of greenhouse gas reductions, technical and economic synergies, and reduced dumping of environmentally harmful products in developing countries.

The report, *Overview of the Market on Refrigerating Appliances and Room Air Conditioners in Eastern and Southern Africa*, [1] outlines the findings of the market assessment that can help policymakers facilitate an effective market transformation to promote energy-efficient and climate-friendly room ACs and residential refrigerators in countries of East African Community (EAC) and Southern African Development Community (SADC). The following are key findings from the report:

- Only 6 countries out of the 21 countries in SADC and EAC regions have minimum energy performance standards (MEPS) (3 mandatory and 3 voluntary) in place for either refrigerators or ACs.
- The AC MEPS in those countries, except for Rwanda, are roughly 3.0-3.2 in terms of the traditional energy efficiency ratio (EER).
- Rwanda's National Cooling Strategy established MEPS and energy labels for room ACs with energy-efficiency requirements and refrigerant GWP limits based on U4E Model Regulation Guidelines with adjustments.
- In SADC, standards in Mauritius and Seychelles are largely aligned with South Africa.
- Only five countries (Kenya, Rwanda, Mauritius, Seychelles and South Africa) have or are developing product registration databases.
- It seems common to find mixed labels from countries of origin of the products, which are not directly comparable to each other and confuse consumers.
- It is expected that by 2040 the electricity demand for both products will grow in both regions by more than 1.5 times. At the same time, room ACs represent a remarkable potential to reduce energy demand.

- If policies are implemented, the adoption of energy efficient-and climate-friendly products in both regions is estimated to save over 5.6 TWh of electricity by 2040. These electricity savings are equivalent to three power plants of 500 MW, reduced CO_2 emissions of 4.6 million tonnes and 506 million USD through reduced electricity bills.

This technical note particularly supports EAC and SADC's effort to establish and improve energy-efficiency standards for room ACs by providing an overview of global market and policy trends and technical recommendations in a harmonized way across the region. The remainder of this report is organized as follows. Section 2 offers the technical context and background. Section 3 gives an overview of AC energy-efficiency and refrigerant trends. Section 4 through 6 provide technical notes and recommendations based on the U4E Model Regulation Guidelines. Section 7 offers an overview and key elements of compliance infrastructure associated with energy efficiency standards for room ACs.

2. Technical context and background

Air conditioning (AC) systems have been developed to improve thermal comfort and air quality in indoor spaces by lowering temperature and humidity. The main types of room ACs are described as below:

Self-Contained Type

This AC type consists of an encased assembly designed as a self-contained unit primarily for mounting in a window or through the wall or as a console ducted to the outdoors. In the window or wall-type ACs (also called single-package, or package terminal ACs) all the components, i.e. the compressor, condenser, expansion valve, and cooling coil; are enclosed in a single housing. They are easy to install and can be removed and stored during the off-season. The cooling capacities tend to be smaller, and some units may be noisier than other types when operating. They are generally less efficient and, due to size constraints, have fewer options to improve efficiency. A portable AC is a self-contained unit, similar to a window air conditioner. It is typically designed with wheels to allow it to be moved. Water condensed from portable AC may be collected in a bucket for manual removal, drained through a gravity hose, or evaporated and exhausted with the condenser process air [4].

Non-ducted Split Type

Ductless split ACs include an indoor and an outdoor unit, connected by refrigerant piping. They are common in the residential and commercial sectors almost everywhere except in the United States, where ducted systems currently dominate.[1] They are up to 30% more efficient given the hot side is separated from the cold side, without heat transmission between them (unlike window air conditioners). These systems may be larger in capacity and are generally installed by trained technicians [4].

Fixed-Speed and Variable-Speed Systems

Fixed-speed ACs (also known as non-inverter units) refer to systems with a fixed-speed compressor where the unit turns on and off to maintain room temperature. Variable-speed ACs (also known as inverter units) use a compressor controlled with a variable speed drive (VSD). They can vary the speed of the compressor, delivering precise cooling as required. Variable-speed units are more efficient when operating at part-load (i.e. not at their maximum capacity). Since most systems are designed to meet cooling conditions occurring rarely, operation at part-load is more frequent, making variable-speed (inverter) units more efficient than fixed-speed (non-

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[1] Residential ACs in North America are dominated by window-type room ACs and split system (ducted) central ACs. In the U.S., window-type room ACs are rated with the Combined Energy Efficiency Ratio (CEER), which is a combination of the EER and standby/off mode power consumption. Split system central ACs (both ducted units and ductless mini-split units) are rated with SEER.

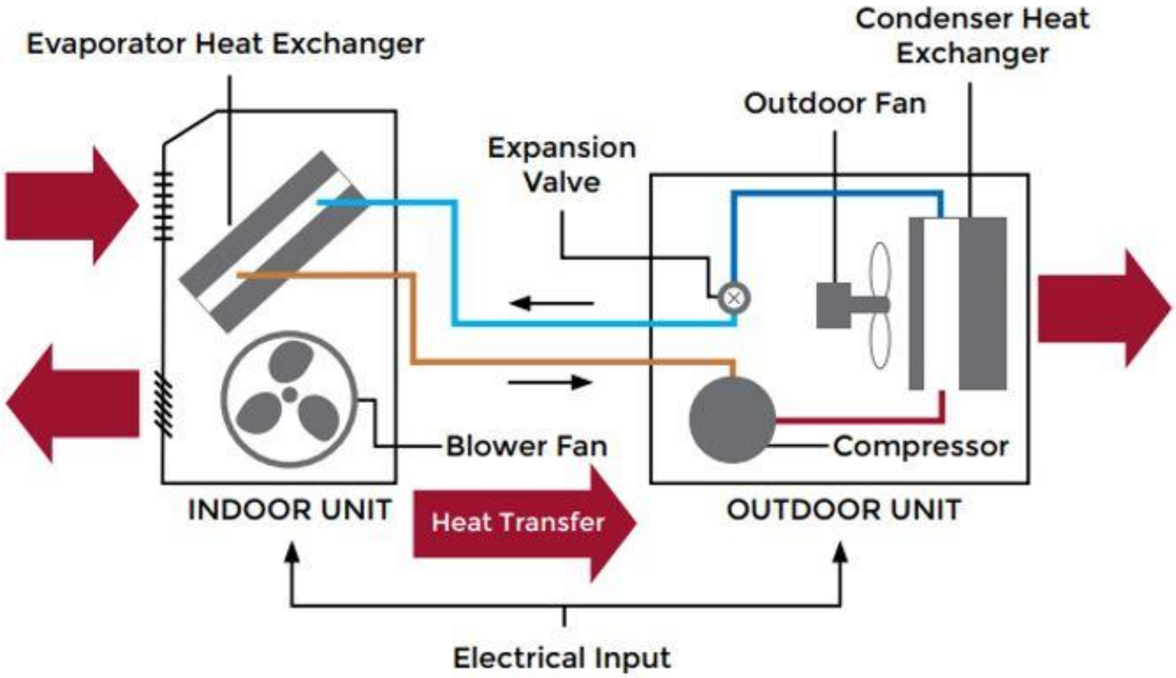
inverter) units [4]. Table 1 summarizes advantages and disadvantages of these main types of room ACs.

Table 1. Main types of room ACs

Type		Advantages	Disadvantages
Window		• Low purchase price • Easy to install • Can be placed either in windows or wall openings.	• Low efficiency • Noisier operation • Improper installation can result in significant air leakage.
Portable		• Lower purchase price • Can be moved from room to room • Easy to install.	• Typically less efficient: lower efficiency at hot climate / better efficiency when the outdoor air temperature is low • Noisier operation • Water needs to be removed manually.
Non-ducted split		• More efficient than window air conditioners • Quieter operation as the compressor sits in the outdoor unit	• Typically higher purchase price than window air conditioners • Installation requirements • Space requirements for outdoor units.
Variable-speed (inverter)		• More efficient than non-inverter units • Achieves desired temperature quicker and no temperature fluctuations	• Typically higher purchase prices than non-inverter units

Source: [4]

The cooling process is based on the application of a refrigeration cycle removing unwanted heat from an area and transfers it to another area, by using an external source of energy. In general, ACs use an electric-driven vapor compression cycle. The vapor compression cycles are performed by refrigerants, in a process comprising four sequential steps: 1) compression; 2) condensation; 3) expansion; and 4) evaporation. In ACs, the cooling effect is used to lower indoor air temperature passing through the evaporator coil, while the absorbed heat is rejected outdoors by the condenser coil [2]. Figure 1 shows the basic AC vapor compression cycle with the main components of a split type. The indoor unit produces a cooling effect inside the room. It is a box-type housing in which some parts of the AC are enclosed: the evaporator coil, air filter, blower fan, drain pipe, and louvers or fins. The outdoor unit contains some parts of the split air conditioner: compressor, condenser, condenser cooling fan and expansion valve.



- The compressor compresses the refrigerant and increases its pressure before sending it to the condenser. During this process, heat is generated in the compressor and removed through heat exchangers to the outdoor ambient.
- The condenser removes the heat from the refrigerant. It is made of coiled copper or aluminum tubing, which has a high rate of conduction. It is covered typically with aluminum fins so the heat from the refrigerant can be removed at a faster rate.
- The expansion valve is used to lower the temperature and pressure of the refrigerant.

Source: [4]

Figure 1. Basic air conditioning vapor compression cycle

Although energy-efficiency in room ACs have improved over the decades, further improvement can be achieved through various measures [4]-[6]. They include the use of more efficient technologies and components such as inverter/variable speed compressors, fans, heat exchangers, expansion devices, and refrigerant fluids. If applied together, these improvement options could reduce the AC energy use by 60 – 72% compared to a base case model defined as a non-inverter split AC model [4], [5] (see Table 2).

Table 2. Classic Efficiency Improvement Options and Corresponding Energy Savings

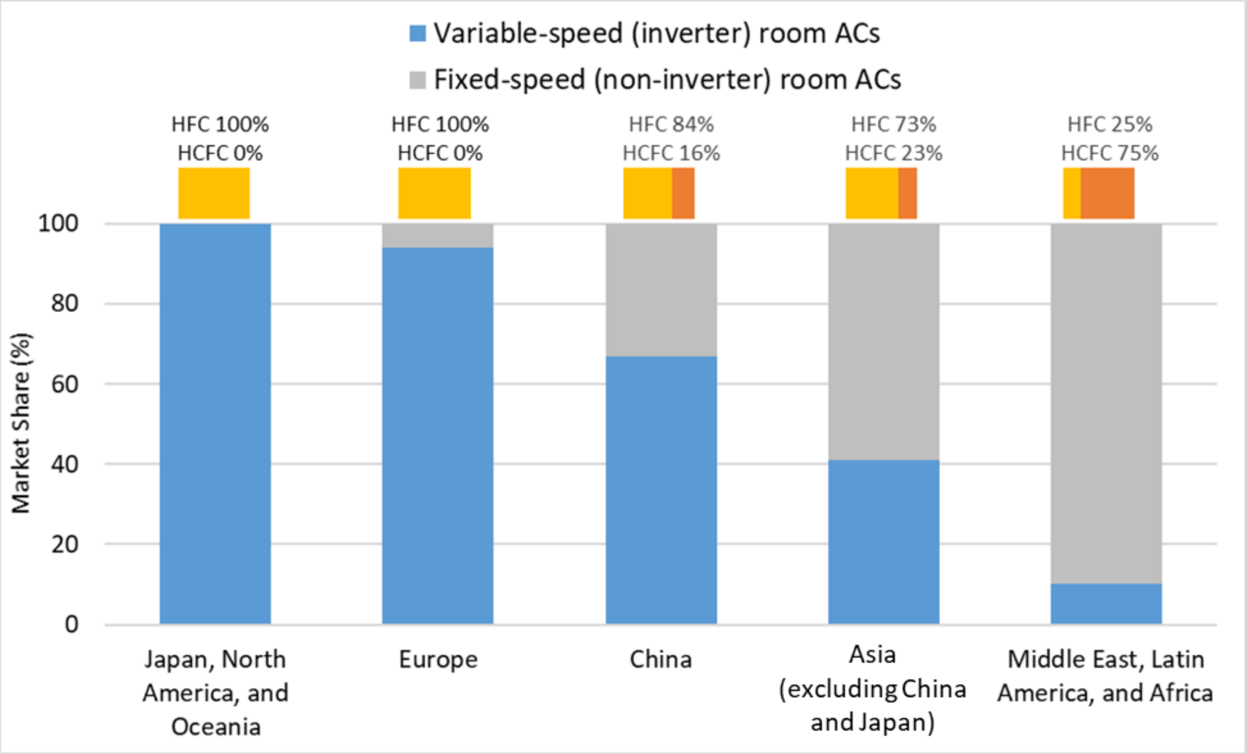
Design option	Description	% improvement from base case
Efficient heat exchanger	High-efficiency microchannel heat exchangers, larger sized heat exchangers	9-29%
Efficient compressors	Two-stage rotary compressors, high-efficiency scroll compressors with DC motors	6-19%
Inverter/Variable Speed	AC, AC/DC or DC inverter-driven compressors	20-25%
Expansion valve	Thermostatic and electronic expansion valve	5-9%
Crankcase heating	Reduced crankcase heating power and duration	10-11%
Standby load	Reduced standby loads	2%
Total/Cumulative		60-72%

Cumulative efficiency improvement is lower than a simple addition as the options are not mutually exclusive, i.e. improvement using one option reduces the baseline energy consumption to which the next efficiency improvement option is applied. Also, the improvements due to variable speed drives are climate and usage dependent.
Source: [5]

3. Overview of air-conditioner energy-efficiency and refrigerant trends

Although designs and configurations vary by regional market, most room ACs sold today use a vapor-compression refrigeration cycle. This technical note focuses on ductless split ACs, because the global room AC market is dominated by this type of unit, known in the United States as mini-split ACs. In the United States, Canada, and Mexico, room ACs are typically understood to be window-type units [7].

Fixed-speed room ACs using high global warming potential (GWP) and ozone-depleting R-22 refrigerant still dominate the market in many emerging economies. Variable-speed units dominate mature AC markets such as Australia, Europe, Japan, South Korea, and the U.S. (Figure 2). The market share in sales of variable-speed room ACs in China, the world's largest room AC market, increased from 8% in 2007 to over 50% in 2016. In India, Brazil, and South Africa, variable-speed ACs are achieving sales market shares of about 30%, 50%, and 60%, respectively [7]-[9].



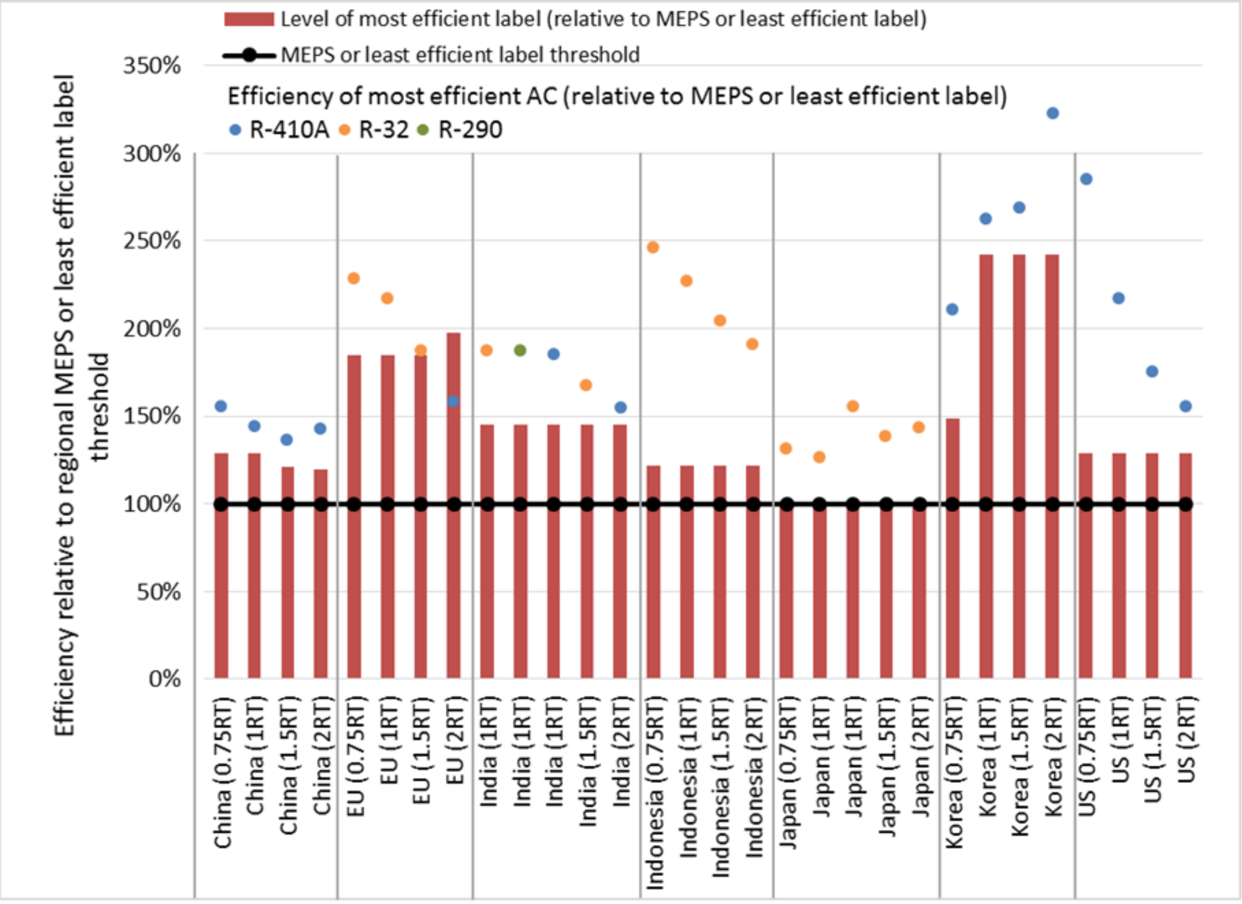
HCFC = hydrochlorofluorocarbon, HFC = hydrofluorocarbon

Source: [10]

Figure 2. Inverter (variable-speed) AC share of AC sales in 2017 by refrigerant type and location

Because of the prevalence of fixed-speed units using R-22 in many markets among developing economies (i.e., A5 Parties), there is significant opportunity to improve room AC efficiency and transition to low-GWP refrigerants using commercially available technology and to design market-transformation programs for high-efficiency, low-GWP equipment, including standards, labeling, procurement, performance assurance requirements for imports, and incentive programs.

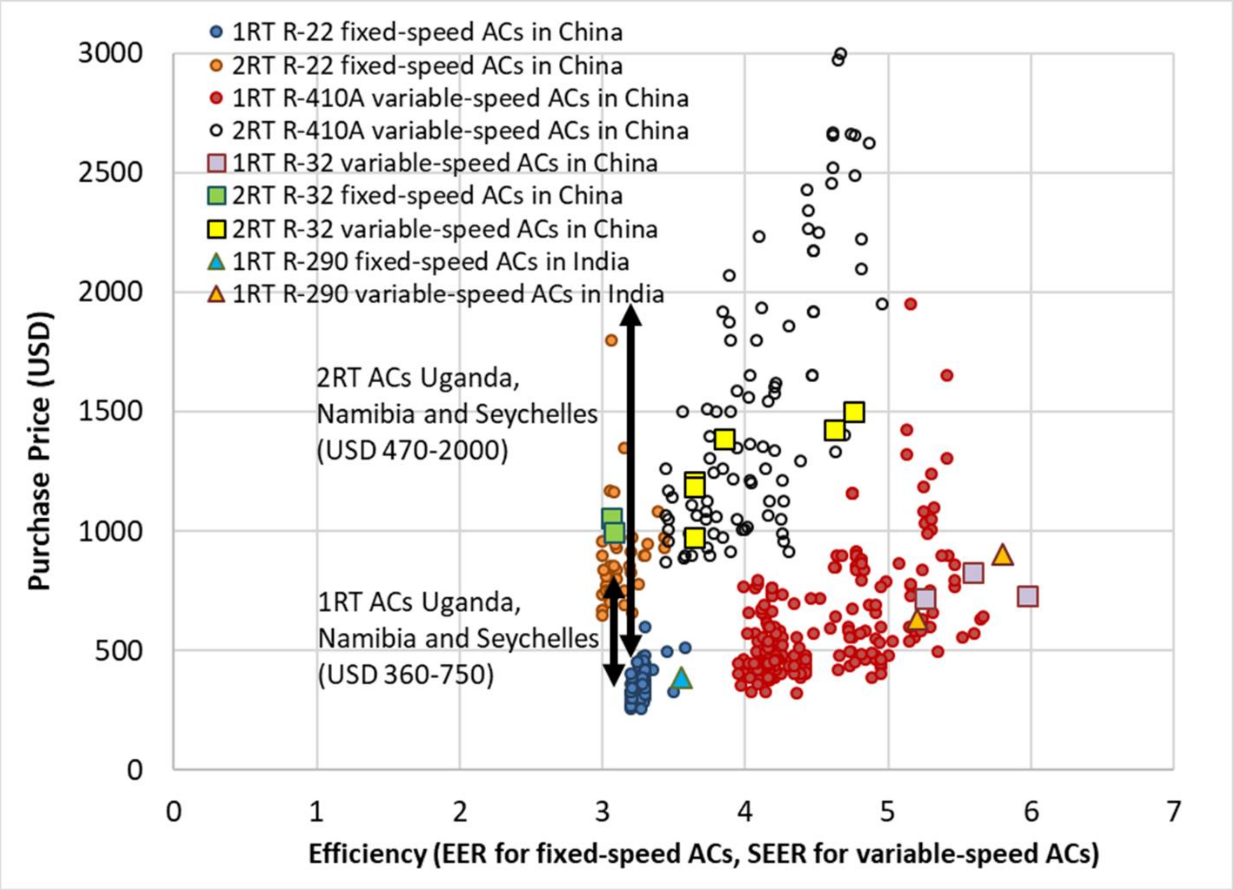
Where R-22 is being phased out, high-GWP R-410A still dominates room AC sales in most mature markets except Japan, where R-32 dominates. R-290 room ACs are available in India [7]. Figure 3 shows that the most efficient models are significantly more efficient (in regional efficiency metric terms) than the most efficient level recognized by energy efficiency standards and labeling programs in the economies where the models are available.



For example, the blue dot and red bar at "US (0.75RT)" should read that the efficiencies of the most efficient U.S. RAC (11.7 W/W) and the most efficient label (ENERGY STAR) requirement (5.27 W/W) are 2.85 times (285%) and 1.29 times (129%) as high as the U.S. MEPS (4.1 W/W). See Table B1 in Appendix B for information on AC models analyzed. Source: [7]

Figure 3. Efficiency of most-efficient models relative to MEPS or least-efficient labels (2016)

Higher-efficiency products tend to have a wider range of market price compared with lower-efficiency products, partly because high-efficiency models are often also sold as premium products bundled with other features. Figure 4 shows an example of efficiency vs associated retail prices of room ACs in China and India. Highly efficient, cost-competitive room ACs with low-GWP refrigerants such as R-32 and R-290 are also commercially available [6]. According to a market assessment for EAC and SADC regions, prices of typical 1RT (equivalent to 3.5 kW and 12,000 Btu/h) and 2RT (equivalent to 7 kW and 24,000 Btu/h) ACs in Uganda, Namibia, and Seychelles are in ranges of USD 360-750 and USD 470-2000, respectively [1]. Figure 4 also shows the price ranges, assuming that their average efficiency is roughly 3.0-3.2 in EER.



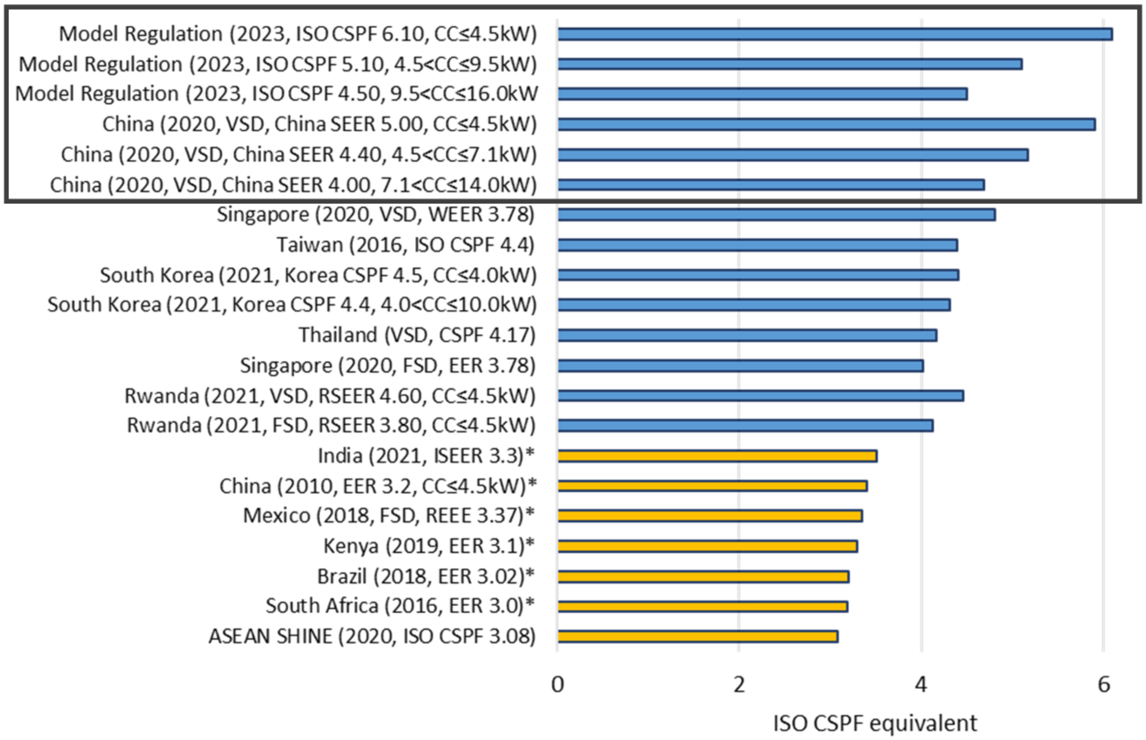
SEER: seasonal energy efficiency ratio; RT: refrigerator ton (1 RT = 3.52 kW)

Thirty of 211 1-RT variable-speed units (R-410A and R-32) meet China SEER (or ISEER) 5 or higher with a price less than USD 1,000. Twenty of 98 2-RT variable-speed units (R-410A and R-32) meet China SEER 4 or higher with a price less than USD 1,500.

Source: [1], [7]

Figure 4. Price vs. efficiency of 1-RT and 2-RT room ACs

China has revised MEPS for variable- and fixed-speed ACs in 2020, and plans to adopt common MEPS levels for both types in 2022. These levels largely align with the U4E Model Regulation Guidelines' minimum efficiency requirements for ACs (Figure 5).



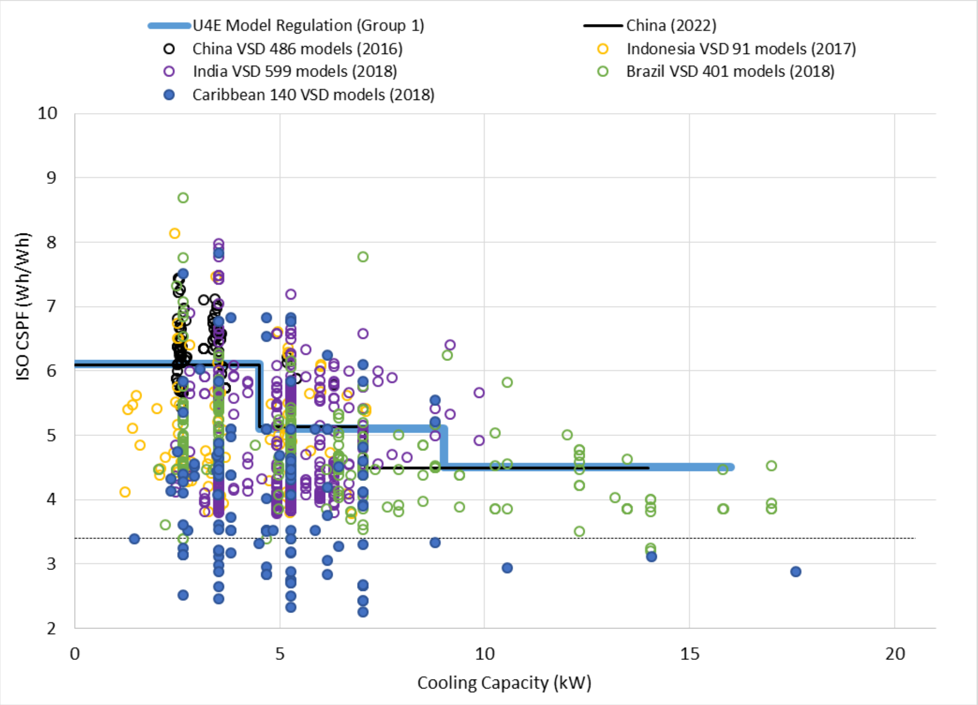
FSD: fixed-speed drive; VSD; variable-speed drive

ISO CSPF for fixed-speed AC units results in a linear relationship with EER, i.e., CSPF = α × EER (e.g., α=1.062 with the ISO reference temperature bin hours), e.g., The CSPF for an EER 3.2 fixed-speed AC is ~3.40.

Source: Authors' work

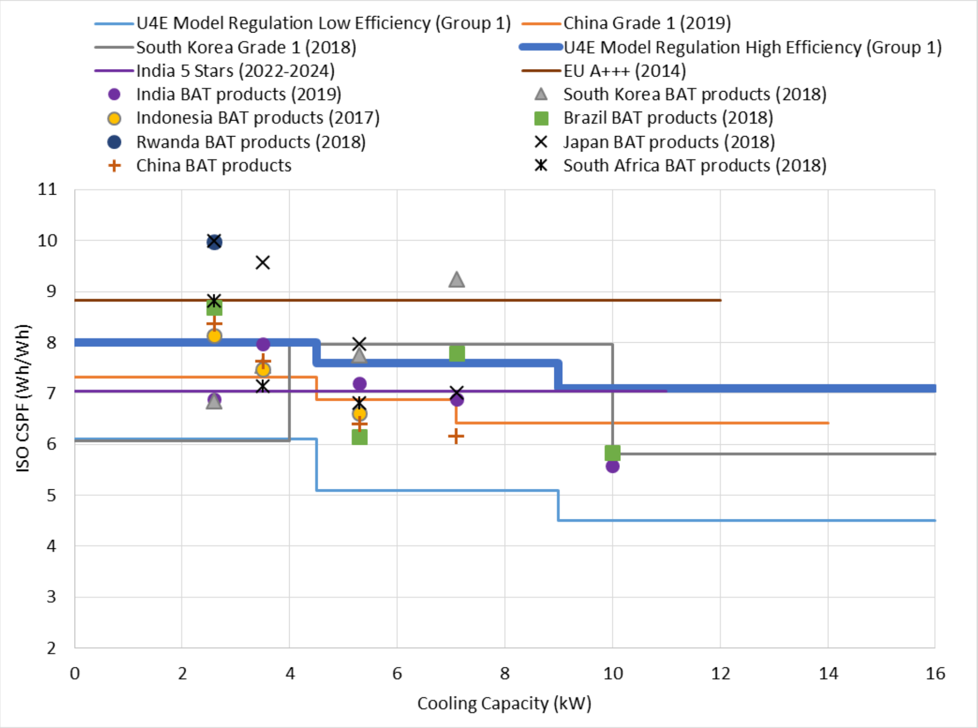
Figure 5. Comparison of AC MEPS in selected economies

Although the majority of fixed-speed AC models are unlikely to meet the China 2022 MEPS and the U4E Model Regulation Guidelines efficiency requirements, 12–26% of variable-speed AC models currently available in major emerging economies are estimated to meet the levels proposed for China 2022 or the U4E Model Regulation Guidelines (2023 or later) (see Figure 6). ACs that surpass the highest efficiency levels recognized by existing labeling programs are available in most regions (see Figure 3 and Figure 7). Of 1,777 single-split, variable-speed AC models in Thailand, the second largest room AC production base, 1,068 models meet the U4E Model Regulation Guidelines efficiency requirements (Figures 8).



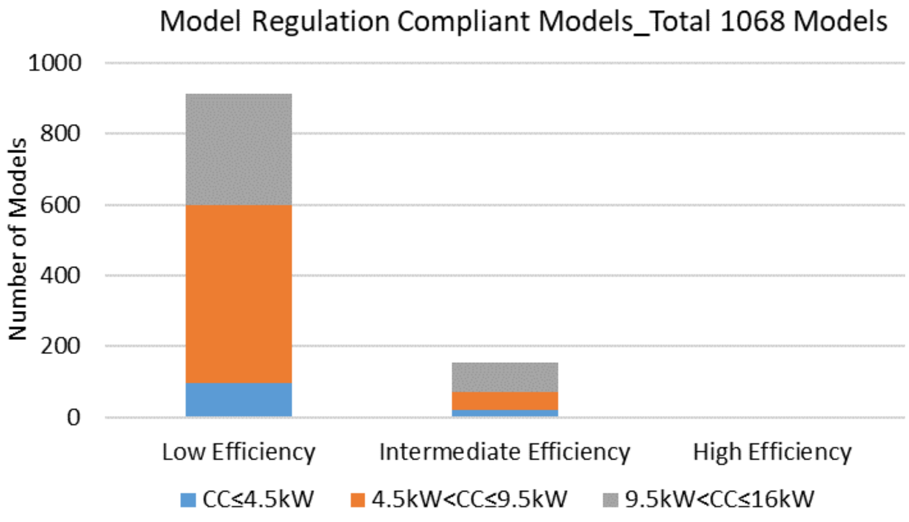
Source: [3]

Figure 6. Efficiency in ISO CSPF estimated for variable-speed ACs available in selected economies



Source: [3]

Figure 7. Top efficiency of the Model Regulation, and regional standards, and most efficient models



U4E Model Regulation Labeling Requirements	Low Efficiency	Intermediate Efficiency	High Efficiency
CC ≤ 4.5 kW	6.10 ≤ CSPF < 7.00	7.10 ≤ CSPF < 8.00	CSPF ≥ 8.00
4.5 kW < CC ≤ 9.5 kW	5.10 ≤ CSPF < 6.40	6.40 ≤ CSPF < 7.60	CSPF ≥ 7.60
9.5 kW < CC ≤ 16.0 kW	4.50 ≤ CSPF < 5.80	5.80 ≤ CSPF < 7.10	CSPF ≥ 7.10

Source: [11]

Figure 8. AC models in Thailand that meet the U4E Model Regulation efficiency requirements

The expected market and technology transition via standards and labels in major emerging economies provides an important policy signal to manufacturers that also sell to markets that are the target of the U4E Model Regulation Guidelines: those with outdated, unenforced, or no MEPS and labels. A common set of requirements will help manufacturers prepare to offer products that can be sold in a larger set of markets, to unlock greater economies of scale so that energy-efficient solutions are widely accessible. Combining the transition toward higher efficiency with the transition toward low-GWP refrigerants would allow the industry to exploit synergies in redesigning equipment and retooling manufacturing lines to achieve both goals simultaneously.

Refrigerants have changed several times, with the goal of improving safety and performance and reducing environmental impacts. First-generation refrigerants were non-fluorinated substances such as hydrocarbons (HCs), ammonia (NH_3), and carbon dioxide (CO_2). Second-generation refrigerants were chlorofluorocarbons (CFCs, e.g., R-12) and HCFCs (e.g., R-22), which are efficient, non-flammable, and non-toxic, but ozone-depleting and high GWP. Third-generation refrigerants are HFCs (e.g., R-410A and R-134a), which are non-ozone depleting but often have high GWP. Until 2012, most AC manufacturers making a transition from R-22 chose R-410A, which is now the most widely used refrigerant in high-efficiency room ACs. However, from about 2012, some Japanese manufacturers began a second transition from R-410A to R-32. The Indian manufacturer Godrej leapfrogged R-410A and is making the transition directly from R-22 to R-

290. These transitions represent the trend toward fourth-generation refrigerants, which include low-GWP HFCs (e.g., R-32), hydrofluoroolefins (HFOs) or HFO blends (e.g., R-452B, R-1234yf), and natural refrigerants such as HCs (e.g., R-290) [7], [12]. Although current technologies, including high-GWP refrigerants, can provide high-efficiency performance, the ongoing transition to low-GWP refrigerants poses challenges for manufacturers developing and deploying new products. Table 3 shows time frames and examples for each generation of refrigerants.

Table 3. Refrigerant transitions over time

Refrigerant Category	Time Frame	Example Refrigerants
1st Generation ("Toxic and Flammable")	1830–1930	HCs (butane, propane, naphtha, gasoline), NH_3, carbon disulfide, carbon dioxide, carbon tetrachloride, dichlorethylene, ethane, ethylamine, ethyl bromide, methyl bromide, methyl formate, methylene chloride, methylamine, methyl chloride, trichloroethylene, and trimethylamine (Andersen et al., 2013)
2nd Generation ("Safe and Durable") but Ozone-Depleting	1931–1990	CFCs, HCFCs (e.g., R-12, R-22)
3rd Generation ("Ozone-safe")	1990–2010	HFCs (e.g., R-410A, R-134a)
4th Generation ("Ozone-safe and Lower GWP")	2010–now	Low-GWP HFCs and blends (e.g., R-32 and R-452B), low-GWP HFOs (e.g., R-1234yf), and HCs (e.g., R-290), and others
5th Generation ("Super-efficient and Sustainable" Low-GWP)	Future	

Source: [7]

HCFCs are scheduled to be phased out in developed countries by 2030 and in developing countries by 2040. Non-ozone depleting HFCs are commercially available alternatives to HCFCs. Since the HCFC phase-out was agreed, annual HFC consumption has increased at a rate of 10 – 15% per year, raising the alarm to their potential contribution to rising global temperatures. Avoiding HFCs' production and use by using technologically feasible low-GWP substitutes could avoid as much as 0.5 °C warming by the end of the century. Under the Paris Agreement, countries have also pledged to reduce GHG emissions through mitigation actions described in their nationally determined contributions (NDCs). Close to half the parties of the United Nations Framework Convention on Climate Change (UNFCCC) have mentioned HFCs in their NDCs - a clear sign that the mitigation of HFCs is necessary to achieving GHG emissions reductions [4]. Manufacturers consider alternatives to transition to climate-friendly refrigerants in room ACs (i.e. substances with zero ODP and low GWP). The refrigerant options include:

- HCFC-22, used to be the refrigerant of choice and will be fully phased out by 2040; HFC-410A, has been deployed as a non-HCFC alternative to HCFC-22. Its use will be increasingly restricted under the Kigali Amendment to the Montreal Protocol.
- HFC-32, has been deployed as a non-HCFC alternative to HCFC-22 and as a lower-GWP alternative to HFC-410A but with a GWP of 675 to be restricted under the Kigali Amendment.
- R-444B, R-446A, R-447B, R-452B and R-454B, are HFO blends currently developed as lower GWP alternatives to HFCs but with GWPs ranging from 300 to 680 to be restricted under the Kigali Amendment;
- R-290, known as propane, a non-HFC alternative with a GWP of 3 and high flammability.

4. Scope of coverage and exemptions

The scope of this technical note includes the most popular types of residential ACs; self-contained ACs, non-ducted split ACs, and portable ACs, with a rated cooling capacity up to 16 kW.

The following products are exempt from this technical note:

a) water-cooled ACs,
b) water-source heat pumps,
c) multi-split ACs,
d) multi-split air-to-air heat pumps, and
e) ducted equipment

5. Terms and definitions

Definitions of the relevant terms in this document are listed, below. Unless otherwise specified, these definitions are harmonized with definitions in ISO 16358:2013 “Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors (Part 1, 2, and 3)”, ISO 5151:2017 “Non-ducted air conditioners and heat pumps – Testing and rating for performance”, ISO 18326:2018 “Non-ducted portable air-cooled air conditioners and air-to-air heat pumps having a single exhaust duct – Testing and rating for performance”, and ANSI/ASHRAE Standard 169-2013 “Climatic Data for Building Design Standards” for climate zone definitions.

Annual Performance Factor (APF)

The ratio of the total amount of heat that the equipment can remove from and add to the indoor air during the cooling and heating seasons in active mode, respectively, to the total amount of energy consumed by the equipment for both seasons.

Climate Group

Defined by thermal criteria using the heating and cooling degree-days and moisture criteria using monthly average temperature and precipitation.

Coefficient of Performance (COP)

The ratio of the heating capacity in Watts to the effective power input in Watts at given rating conditions.

Cooling Seasonal Energy Consumption (CSEC)

The total amount of energy consumed by the equipment when it is operated for cooling during the cooling season.

Cooling Seasonal Performance Factor (CSPF)

The ratio of the total annual amount of heat that the equipment can remove from the indoor air when operated for cooling in active mode to the total annual amount of energy consumed by the equipment during the same period.

Cooling Seasonal Total Load (CSTL)

The total annual amount of heat that is removed from the indoor air when the equipment is operated for cooling in active mode.

Double-duct Portable Air Conditioner

An encased assembly or assemblies designed primarily to provide delivery of conditioned air to an enclosed space, room or zone which takes its source of air for cooling the condenser from the outdoor space by a duct, and discharges this air through a second duct, and which is placed wholly inside the space to be conditioned.

Double-duct Portable Heat Pump

An encased assembly or assemblies, which is placed wholly inside the space to be conditioned, designed primarily to provide delivery of conditioned air to an enclosed space, room or zone and includes a prime source of refrigeration for heating and which takes its source of air for the evaporator from the outdoor space by a duct.

Ductless Air Conditioner

An encased assembly or assemblies designed primarily to provide delivery of conditioned air to an enclosed space, room or zone.

Ductless Heat Pump

An encased assembly or assemblies designed primarily to provide delivery of conditioned air to an enclosed space, room or zone and includes a prime source of refrigeration for heating.

Note: Reversible unit works in either direction to provide cooling or heating to the space

Energy Efficiency Ratio (EER)

The ratio of the total cooling capacity to the effective power input to the device at given rating conditions. (An alternate definition of EER is a ratio of the cooling capacity delivered by a system in BTU/h to the power consumed by the system in watts (W) at any given set of rating conditions. 1 BTU/h is equivalent to 0.293 W.

Heating Seasonal Total Load (HSTL)

The total annual amount of heat, including make-up heat, which is added to the indoor air when the equipment is operated for heating in active mode.

Heating Seasonal Energy Consumption (HSEC)

The total annual amount of energy consumed by the equipment, including make-up heat, when it is operated for heating in active mode.

Heating Seasonal Performance Factor (HSPF)

The ratio of the total annual amount of heat that the equipment, including make-up heat, can add to the indoor air when operated for heating in active mode to the total annual amount of energy consumed by the equipment during the same period, calculated by HSTL over HSEC.

6. Requirements

6.1 Test method

The ISO 5151 testing standard specifies how to measure ACs' cooling capacity and efficiency using stipulated test conditions. There are several sets of conditions which are representative for different climates. Condition T1, which specifies indoor and outdoor temperatures at moderate climates, is used by most countries.

The ISO 16358 is a newer standard based on the ISO 5151 test points. It allows fixed- and variable-speed ACs to be rated under the same metric and product category, capturing part-load savings from inverters and provides flexibility in adopting a country-specific temperature bin (i.e., a representation of the country’s year-round cooling demands). ISO 16358 was adopted as an ISO standard in 2013, and many countries[2] have already adopted it in their regulations. The test points required by ISO 16358 are based on the ISO 5151 T1 climate condition, facilitating its adoption because additional testing is not required.

The ISO CSPF calculation for fixed-speed units requires two sets of test data: measurement of performance (capacity and power input) at full-capacity operation at 35°C and 29°C. However, in practice, countries require only one set of test data at full-capacity operation at 35°C and use another set of data points at 29°C calculated by predetermined equations, resulting in no

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[2] Australia (for labels), Japan, India, Indonesia, Malaysia, Myanmar, Philippines, Cambodia, Thailand, Vietnam, Lao PDR, Hong Kong, Brazil, Rwanda, etc. China’s SEER and Korea’s CSPF are largely consistent with ISO CSPF.

additional or different requirement for testing fixed-speed units compared to using the EER metric (see Table 4).

CSPF/SEER calculations for variable-speed units require two or three sets of test data at 35°C and another set of data points at 29°C calculated by ISO 16358-determined equations. Minimum-capacity tests are typically conducted at the lowest-capacity control settings of units that allow steady-state operation at the given test conditions. In China, the minimum-capacity test is conducted at 25% of full capacity (see Table 5).

Table 4. Test conditions for fixed-speed units

Operating condition	Outdoor dry bulb temperature	EER	China (SEER), South Korea (CSPF), U4E Model Regulation	ISO 16358 (CSPF)
Full capacity and power input	35°C	Required	Required	Required
Half capacity and power input		NA	NA	NA
Minimum capacity and power input		NA	NA	NA
Full capacity and power input	29°C	NA	Calculated[a]	Required
Half capacity and power input		NA	NA	NA
Minimum capacity and power input		NA	NA	NA

a. Capacity(29℃)=Capacity(35℃)×1.077; Power input(29℃)=Power input(35℃)×0.914. Given that predetermined equations are used to estimate the performance at 29°C, CSPF for fixed-speed units results in a linear relationship with EER:

CSPF = 1.062 × EER ………………………………………… Eq. (1)

Table 5. Test conditions for variable-speed units

Operating condition	Outdoor dry bulb temperature	WEER[a]	Japan, India, China (CC ≤ 7.1 kW) U4E Model Regulation	ISO 16358 (CSPF)
Full capacity and power input	35°C	Required	Required	Required
Half capacity and power input		Required	Required	Required
Minimum capacity and power input		NA	NA	Optional
Full capacity and power input	29°C	NA	Calculated[b]	-
Half capacity and power input		NA	Calculated[b]	Optional
Minimum capacity and power input		NA	NA	Optional

[a] Weighted COP (WCOP) or WEER used in Singapore, defined as 0.4 × EER (or COP, 100% load at 35°C) + 0.6 × EER (or COP, 50% load at 35°C).

[b] Capacity(29℃)=Capacity(35℃)×1.077; Power input(29℃)=Power input(35℃)×0.914.

[c] Part load capacities under these conditions are achieved by fixing the compressor speed of the variable-speed unit.

6.2 Performance metrics

The cooling efficiency of an AC has been generally expressed by its EER. The EER is the ratio of the cooling capacity, and the power consumed when measured at full load (i.e., at the maximum deliverable cooling capacity of the air conditioner). This EER has been the basic parameter used to indicate the energy performance of ACs in MEPS and energy efficiency labelling regulations.

Given that ACs typically operate at full load for only a small number of hours in the cooling season, the EER is often not the best representation of AC performance especially for variable-speed systems since the EER does not take into account performance at part-load. Seasonal efficiency metrics consider the impact of variations in outdoor temperature on cooling load and energy consumption, requiring (or optionally allowing) multiple test points to compute a seasonally weighted average efficiency. These metrics are intended to represent how the AC would perform over a typical cooling season in a representative building type with typical operating characteristics. The difference in seasonal efficiency metrics is primarily due to the outside temperature profiles used to aggregate steady-state and cyclic ratings into a seasonal efficiency value and the ways of evaluating performance at part-load operation in the metric. Specific parameters to account for AC performance at part-load and/or lower-temperature operation in the efficiency metric vary by country [8], [13].

Outdoor temperature bin hours for AC use are defined as a set of hours at each outdoor temperature that requires cooling. Outdoor temperature bin hours used for calculating seasonal efficiency vary by the regional standard. Table 5 summarizes outdoor temperature bin hours used for seasonal energy-efficiency calculations in select regions [8], [13].

Table 6. Summary of outdoor temperature bin hours used in calculations of seasonal energy efficiency by region

	ISO	China	EU	India	Japan	South Korea	U.S.
Standard	ISO 16358: 2013	GB 21455-2013	EN 14825: 2016	Schedule 19	JIS C 9612: 2013	KS C 9306: 2017	ANSI/AHRI 210/240-2008
Temperature range	21–35°C	24–38°C	17–40°C	24–43°C	24–38°C[c]	24–38°C[c]	65–104°F (18.3–40°C)
Total hours of outdoor temperature bin	1,817	1,136	2,602[a]	1,600	1,569	941	Defined fraction of total temperature bin hours [b]

[a] According to EN 14825:2016, equivalent active-mode hours for cooling are assumed to be 350 hours, while the total hours of outdoor temperature bin equal 2,602 hours.

[b] Bin hours of each outdoor temperature may be calculated by multiplying the fractional bin hours by the total annual cooling hours if the fractional bin hours are applicable. ISO 16358 also provides fractional bin hours.

[C] Although JIS C 9612:2013 and KS C 9306:2017 define outdoor temperature bin hours in the range of 24–38°C, zero hours are actually assigned to 35–38°C in JIS C 9612:2013 and 38°C in KS C 9306:2017.

Source: [8]

The world has diverse climates, varying by region from hot and humid to cold and dry. The U4E Model Regulation Guidelines provide various temperature bin hours by climate region based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zone definitions which are based on cooling degree-day base 10°C (CDD10), heating degree-day base 18°C (HDD18), annual precipitation, annual mean temperature, and so forth. Based on this, the U4E Model Regulation Guidelines provide outdoor temperature bin hours for various climate groups that can be used for energy efficiency performance calculation (Table 6). Climates in EAC and SADC member countries fall largely in the Group 1 climates (see Figure 9, Figure 10, and Table 8).

Table 7. Climate groups in the U4E Model Regulation Guidelines

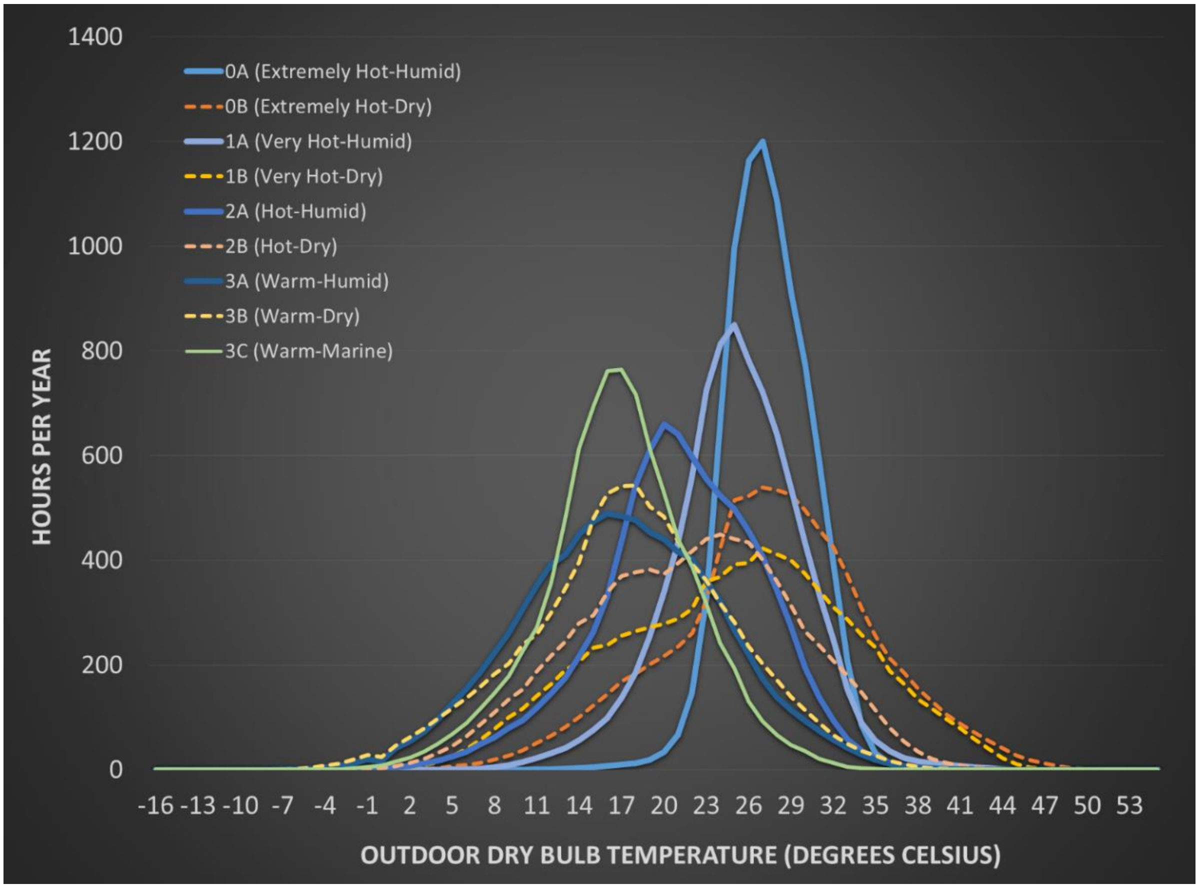
Primary Climate Group[a]	Secondary Climate Group[b]			
	Thermal	**Humid**	**Dry**	**Marine**
Group 1	Extremely Hot	0A (Extremely Hot-Humid)		
	Very Hot	1A (Very Hot-Humid)		
	Hot	2A (Hot-Humid)	2B (Hot-Dry)	
	Warm	3A (Warm-Humid)	3B (Warm-Dry)	3C (Warm-Marine)
Group 2	Extremely Hot		0B (Extremely Hot-Dry)	
	Very Hot		1B (Very Hot-Dry)	
Group 3	Mixed	4A (Mixed-Humid)	4B (Mixed-Dry)	
	Cool	5A (Cool-Humid)	5B (Cool-Dry)	
	Cold	6A (Cold-Humid)	6B (Cold-Dry)	
	Very Cold	7		
	Subarctic/Arctic	8		

[a] For cooling energy efficiency calculation, primary climate group 1 and 3 refer to ISO 16358-1: 2013, and primary climate group 2 refers to ISO 16358:-1 2013/Amd 1:2019.

[b] According to ASHRAE climate zone definitions available at ANSI/ASHRAE Standard 169-2013.

Source: [2]

Figure 6 shows average annual outdoor temperature distribution profiles of the nine hot/warm climate regions. Temperature bin hours for calculating CSPF in these climate regions are available at the U4E Model Regulation Guidelines Supporting Information and Table 7 in this technical note.



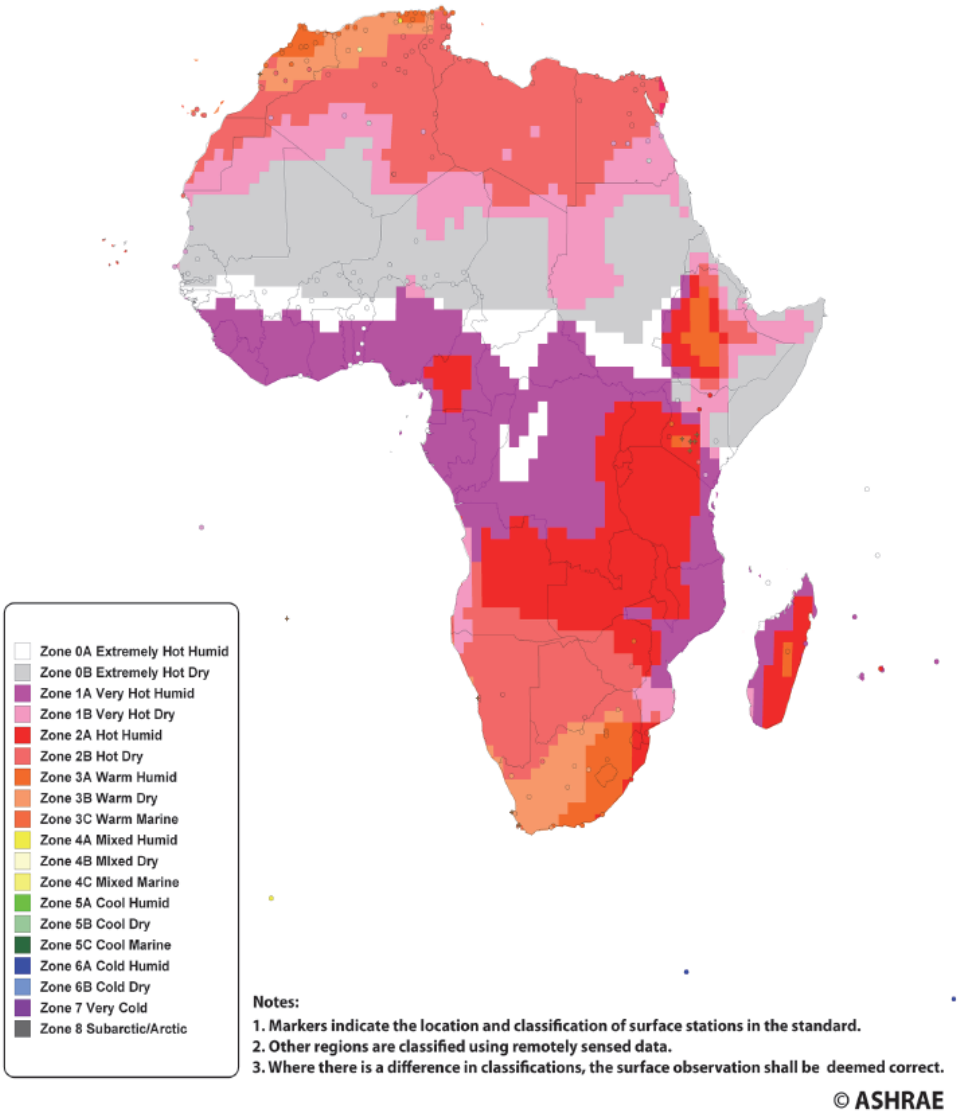
Source: [3] (For illustrative purpose, graphs are adjusted to curves from the original bar charts.)

Figure 9. Annual outdoor temperature distribution of hot/warm climate regions (0A to 3C)

Table 8. Temperature bins for calculating CSPF in Group 1 countries

Outdoor temperature	Reference	0A	1A	2A	3A	2B	3B	3C
℃	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours
21	ISO 16358-1: 2013	5	33	49	32	30	34	34
22		23	86	92	62	64	60	60
23		76	167	128	83	102	84	73
24		205	250	161	99	138	98	75
25		383	327	191	103	169	108	74
26		537	360	210	101	201	109	60
27		646	388	219	93	216	109	50
28		671	395	212	85	221	105	41
29		630	371	188	79	217	97	32
30		596	332	149	72	203	88	27
31		501	285	118	63	200	75	18
32		361	227	86	52	191	61	12
33		206	153	58	41	180	50	6
34		86	90	37	29	147	36	3
35		32	55	22	18	113	27	2
36		11	35	13	11	80	16	1
37		3	22	8	7	53	10	0
38		1	16	4	4	34	6	0
39		0	12	3	2	21	3	0
40		0	10	1	1	13	1	0
41		0	7	1	1	8	1	0
42		0	5	1	0	4	0	0
43		0	3	0	0	3	0	0
44		0	1	0	0	1	0	0
45		0	0	0	0	0	0	0
46		0	0	0	0	0	0	0
47		0	0	0	0	0	0	0
48		0	0	0	0	0	0	0
49		0	0	0	0	0	0	0
50		0	0	0	0	0	0	0
Total	1817	4973	3630	1951	1038	2609	1178	568

Source: [2]



Notes:

1. Markers indicate the location and classification of surface stations in the standard.
2. Other regions are classified using remotely sensed data.
3. Where there is a difference in classifications, the surface observation shall be deemed correct.

© ASHRAE

Source: [13]

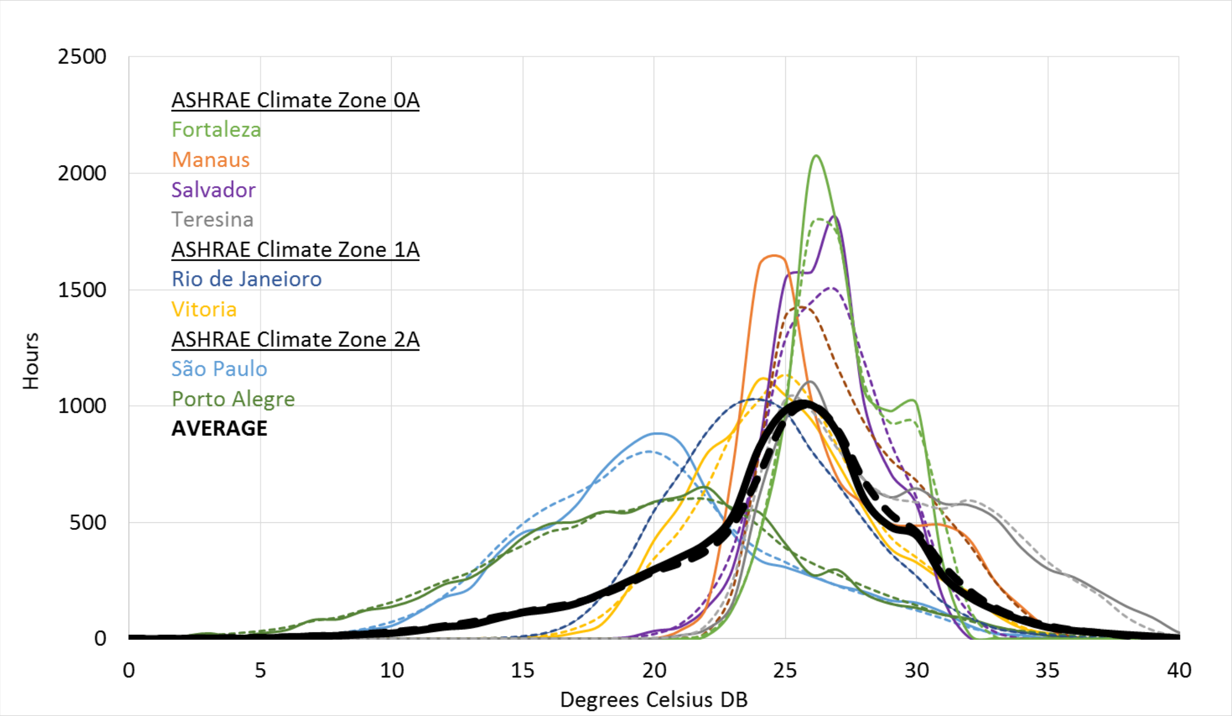
Figure 10. Africa climate zones map

Table 9. EAC and SADC member countries by Climate Group

Country	Primary	Secondary
Angola	1	1A◊
Botswana	1*, 2	1B, 2B*
Burundi	1	1A◊
Comoros	1	0A
Democratic Republic of the Congo	1	1A
Kenya	1	0A, 0B, 1B, 2A*, 2B, 3A, 3C
Lesotho	1	3B◊
Madagascar	1	0A, 1A, 3A*
Malawi	1	3A◊
Mauritius	1	0A, 1A*, 2A
Mozambique	1	1A
Namibia	1	2B
Rwanda	1	2A◊
Seychelles	1	0A
South Africa	1*, 2	1B, 2A, 2B, 3A, 3B, 3C*
South Sudan	2	0B
Uganda	1	2A◊
United Republic of Tanzania	1	0A, 1A*, 2B
Zambia	1	3A◊
Zimbabwe	1	2B, 3A*

a. Secondary climate group is based on the data of ASHRAE weather data viewer 6.0.
b. * represents the climate of the largest population city or region where data available.
c. ◊ represents the climate estimated from other sources than the ASHRAE weather data.
d. The representative climate group may be subject to change with additional information.
Source: [2]

The hours of each temperature bin for AC use can also be determined based on AC use information in the country. For example, the Laboratory for Energy Efficiency in Buildings (LabEEE) at the Federal University of Santa Catarina (UFSC) in Brazil and Lawrence Berkeley National Laboratory (LBNL) analyzed weather data for selected regions in Brazil. Figure 11 shows annual outdoor temperature distributions of the eight cities as analyzed by LabEEE and LBNL.



Source: [8]

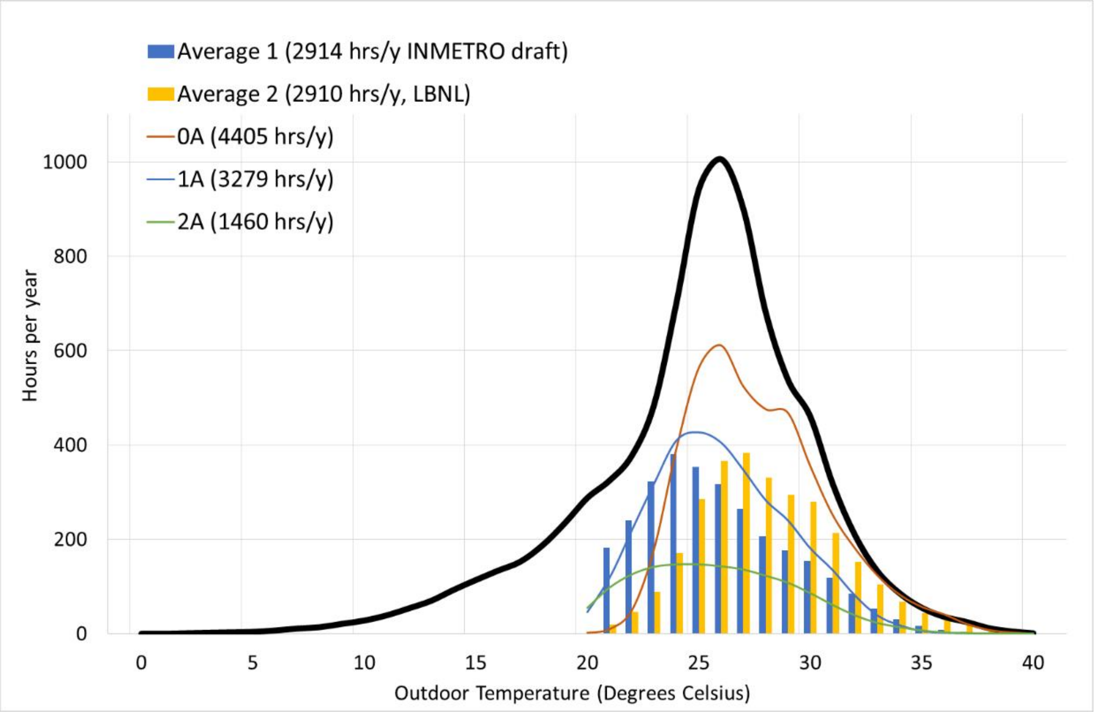
Solid curves represent LabEEE-analyzed outdoor temperature distributions. Dotted curves are LBNL analysis results.

Figure 11. Annual outdoor temperature distribution (8760 hours) of eight regions in Brazil

The blue histogram in Figure 12 shows a set of outdoor temperature bin hours in the draft document for public consultation by the National Institute of Metrology, Quality and Technology (INMETRO). CSPF is calculated as

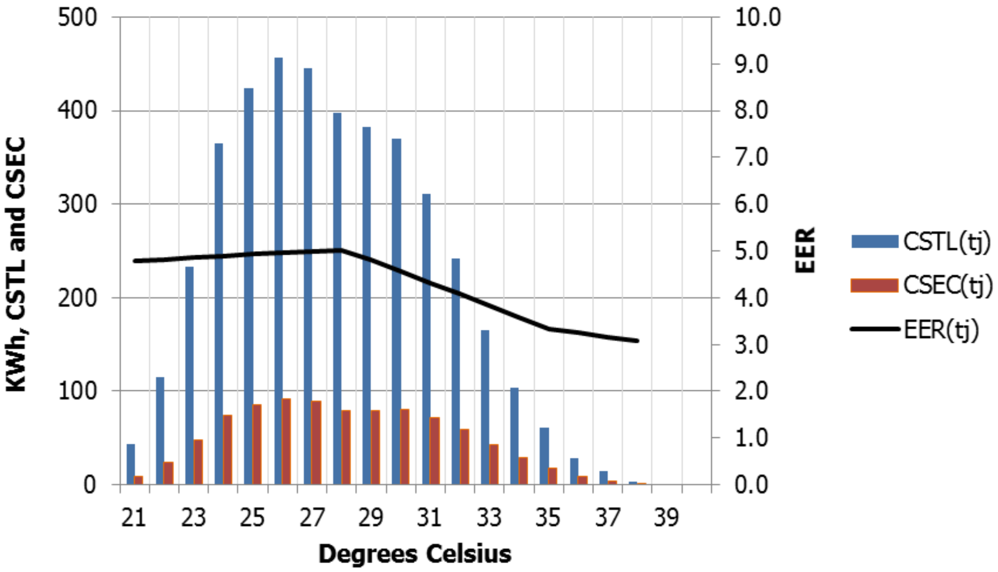
$\sum(cooling\ load \times hours)/\sum(power\ input \times hours)$……………………………………………Eq. (2)

Figure 13 shows cooling load and energy consumption in kWh for a variable-speed AC unit at each temperature according to ISO 16358 and Average 1 (Blue histogram) in Figure 12.



Source: [8]

Figure 12. Annual outdoor temperature distribution (black) and temperature bin hours assumed for AC use in Brazil (yellow and blue)



CSTL(t_j) = cooling load times hours at outdoor temperature t_j
CSEC(t_j) = cooling power input times hours at outdoor temperature t_j
EER(t_j) = EER at outdoor temperature tj
CSPF = $\sum CSTL(tj)/\sum CSEC(tj)$
Source: [8]

Figure 13. Cooling seasonal total load and cooling seasonal energy consumption of a variable-speed AC unit with Average 1 bin hours

6.3 Energy efficiency requirements

Cooling performance for all ductless split and self-contained ACs, except for portable ACs, within the scope of the U4E Model Regulation Guidelines shall meet or exceed the energy performance levels in Table 10, depending on the appropriate secondary climate group, represented by the CSPF metric coupled with climate group-specific outdoor temperature bin hours. Minimum requirement CSPF values according to sub-climate zone-specific outdoor temperature bin hours are available at Table 10.

Table 10. Reference minimum requirements for CSPF of split and self-contained ACs

	Primary	Secondary (optional)						
Category	**Group 1**	**0A**	**1A**	**2A**	**3A**	**2B**	**3B**	**3C**
CC≤ 4.5 kW	6.10	5.70	5.40	5.60	5.40	4.90	5.40	6.00
4.5 kW < CC ≤ 9.5 kW	5.10	4.90	4.70	4.80	4.70	4.30	4.70	5.10
9.5 kW < CC ≤ 16.0 kW	4.50	4.30	4.20	4.30	4.20	4.00	4.20	4.50
Reference Standards	ISO 16358-1:2013							
Outdoor Temperature Bin Hours	ISO 16358-1:2013 Table 3	U4E Model Regulation Guidelines Annex 4 (Table 7 in this technical note)						

CC: cooling capacity. See Table 8 for climates associated with EAC and SADC members, and Table 7 for outdoor temperature bins of each sub-climate group.

Source: [2]

Cooling performance for all portable ACs within the scope of the U4E Model Regulation Guidelines shall meet or exceed the energy efficiency level in Table 11, represented by the EER metric. Portable ACs covered by the U4E Model Regulation Guidelines are placed entirely inside the space to be conditioned, hence the performance evaluation for these products does not use outdoor temperature bin hours used for evaluating the performance of other product types.

Table 11. Reference minimum requirements for EER of portable ACs

Type	EER
All	3.10

Source: [2]

Labels indicating achievement of a higher performance grade may be applied to units that meet or exceed the levels specified in Table 10. Table 12 shows possible thresholds of labeling requirements for ACs. The high-efficiency levels represent approximately 30-60% of the efficiency improvement possible in energy-efficient technologies globally, but less than the efficiency levels of best available technologies that are not necessarily available in all markets.

Table 12. Labeling requirements for ACs in Climate Group 1

Climate Group (Temperature Bin Hours)	Grade	Rated Cooling Capacity ≤ 4.5 kW	4.5 kW < Rated Cooling Capacity ≤ 9.5 kW	9.5 kW < Rated Cooling Capacity ≤ 16.0 kW
Group 1 (ISO 16358-1: 2013)	High Efficiency	8.00 ≤ CSPF	7.60 ≤ CSPF	7.10 ≤ CSPF
	Intermediate	7.10 ≤ CSPF < 8.00	6.40 ≤ CSPF < 7.60	5.80 ≤ CSPF < 7.10
	Low Efficiency	6.10 ≤ CSPF < 7.10	5.10 ≤ CSPF < 6.40	4.50 ≤ CSPF < 5.80
0A (U4E Model Regulation)	High Efficiency	7.40 ≤ CSPF	7.00 ≤ CSPF	6.60 ≤ CSPF
	Intermediate	6.60 ≤ CSPF < 7.40	6.00 ≤ CSPF < 7.00	5.50 ≤ CSPF < 6.60
	Low Efficiency	5.70 ≤ CSPF < 6.60	4.90 ≤ CSPF < 6.00	4.30 ≤ CSPF < 5.50
1A (U4E Model Regulation)	High Efficiency	7.00 ≤ CSPF	6.60 ≤ CSPF	6.20 ≤ CSPF
	Intermediate	6.20 ≤ CSPF < 7.00	5.70 ≤ CSPF < 6.60	5.20 ≤ CSPF < 6.20
	Low Efficiency	5.40 ≤ CSPF < 6.20	4.70 ≤ CSPF < 5.70	4.20 ≤ CSPF < 5.20
2A (U4E Model Regulation)	High Efficiency	7.30 ≤ CSPF	6.90 ≤ CSPF	6.50 ≤ CSPF
	Intermediate	6.50 ≤ CSPF < 7.30	5.90 ≤ CSPF < 6.90	5.40 ≤ CSPF < 6.50
	Low Efficiency	5.60 ≤ CSPF < 6.50	4.80 ≤ CSPF < 5.90	4.30 ≤ CSPF < 5.40
3A (U4E Model Regulation)	High Efficiency	7.00 ≤ CSPF	6.60 ≤ CSPF	6.20 ≤ CSPF
	Intermediate	6.20 ≤ CSPF < 7.00	5.70 ≤ CSPF < 6.60	5.20 ≤ CSPF < 6.20
	Low Efficiency	5.40 ≤ CSPF < 6.20	4.70 ≤ CSPF < 4.70	4.20 ≤ CSPF < 5.20
2B (U4E Model Regulation)	High Efficiency	6.20 ≤ CSPF	5.90 ≤ CSPF	5.60 ≤ CSPF
	Intermediate	5.60 ≤ CSPF < 6.20	5.10 ≤ CSPF < 5.90	4.80 ≤ CSPF < 5.60
	Low Efficiency	4.90 ≤ CSPF < 5.60	4.30 ≤ CSPF < 5.10	4.00 ≤ CSPF < 4.80
3B (U4E Model Regulation)	High Efficiency	6.90 ≤ CSPF	6.50 ≤ CSPF	6.10 ≤ CSPF
	Intermediate	6.20 ≤ CSPF < 6.90	5.60 ≤ CSPF < 6.50	5.20 ≤ CSPF < 6.10
	Low Efficiency	5.40 ≤ CSPF < 6.20	4.70 ≤ CSPF < 5.60	4.20 ≤ CSPF < 5.20
3C (U4E Model Regulation)	High Efficiency	7.90 ≤ CSPF	7.50 ≤ CSPF	7.00 ≤ CSPF
	Intermediate	7.00 ≤ CSPF < 7.90	6.30 ≤ CSPF < 7.50	5.80 ≤ CSPF < 7.00
	Low Efficiency	6.00 ≤ CSPF < 7.00	5.10 ≤ CSPF < 6.30	4.50 ≤ CSPF < 5.80

Source: [2]

6.4 Functional Performance

Within the scope of the U4E Model Regulation Guidelines, all units shall be tested at a test alternating current (AC) voltage and rated frequency, as described in ISO 5151. All units shall operate appropriately with the rated voltage with surge protection +/- 15%.

6.5 Refrigerant

Within the scope of the U4E Model Regulation Guidelines, refrigerants used in ACs shall comply with requirements for ozone depletion potential (ODP) and global warming potential (GWP) over a 100-year time horizon according to Table 13. All units shall comply with standard ISO 5149 or IEC 60335-2-40:2018, a subsequent revision, or a nationally-modified edition of ISO 5149 or IEC 60335-2-40.

Table 13. Requirements for Refrigerant Characteristics (numbers shown are upper limits)

	GWP	ODP
Self-Contained System	150	0
Ductless Split System	750	0

Countries (and sometimes regions within countries) have their own processes and timelines for the development of refrigerant standards. The International Electrotechnical Commission (IEC) Standards for mildly flammable (A2L) and flammable (A3) refrigerants are under revision, and new standards are expected to be available in the next few years. At present, several standards covering use of flammable refrigerants, charge limitation, and related equipment are available in IEC 60335-2-40, ISO 5149, EN 378-1, etc. For systems installed without restrictions of room size, there is a maximum charge size limit of 150 g for flammable refrigerants (A3). If the allowable charge limit for safe use increases to 1 kg, the maximum capacity of mini-split units could reach 7 kW, which would enable room ACs using R-290 to target 80% of the global market. For small self-contained and split systems, ISO 5149 and IEC 60335-2-40 specify the maximum charge size limit of hydrocarbons (HCs) to be 0.3 kg and 1.0/1.5 kg, respectively, and the allowable charge size to be 0.01 x room volume (m^3) or 0.04 x height (m) x room area (m^2), respectively (see Table 14).

Table 14. Refrigerant charge size limits for HCs safety standards for ACs

	IEC 60335-2-40		ISO 5149-1	
	Maximum charge	Allowable charge	Maximum charge	Allowable charge
Small self-contained	0.3 kg	$0.01\times V_{rm}$	0.3 kg	$0.01\times V_{rm}$
Ductless split	1 kg	$0.04\times height\times A_{rm}$	1.5 kg	

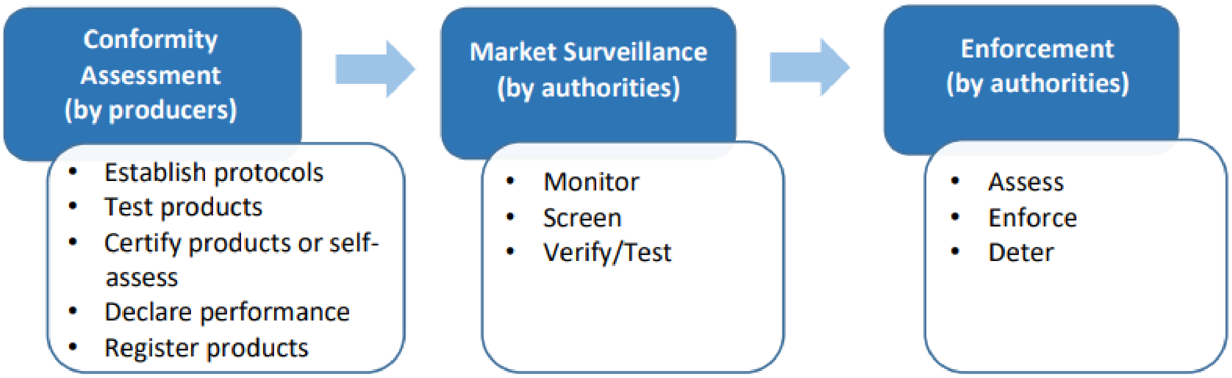
where: V_{rm} = room volume (in m^3); A_{rm}= room area (in m^2) and h = unit installation height (in m)
Source:

7. Compliance

MEPS and labels are critically important in driving market transformation, but they are only useful if products are compliant with energy efficiency limits and that the energy labels are correctly reflecting the performance of the products. Even mature MEPS and labelling programs can experience problems with compliance, and this can occur even for products that have been regulated for many years, and hence its essential for the integrity of programmatic goals to design and implement robust compliance regimes [16].

Compliance frameworks are meant to ensure that suppliers follow necessary steps so that their products comply with requirements and are correctly labelled prior to their placement on the market. The frameworks also help policymakers monitor and verify that products conform over time and take corrective action to deter non-compliance. These actions are essential if the desired energy, economic and environmental benefits are to be achieved while ensuring a free and fair market for legitimate suppliers [16].

The three main pillars for high level of compliance can be distinguished as: conformity assessment, market surveillance, and enforcement (see Figure 14). A focus on all three is necessary. The main body of the report discusses these aspects in turn and sets out guidance on effective implementation. Some actions that support market surveillance are synergistic to those needed for market assessments and feed into impact evaluations [17]. Efforts can be shared across these activities.



Source: [16]

Figure 14. The three pillars of compliance

7.1 Conformity assessment

Conformity assessment is to secure the confidence of consumers and public authorities in the conformity of regulated products, allow fair competition between manufacturers in the conformity of regulated products, and ultimately ensure that the environmental objectives are met. There are multiple compliance pathways. Key distinctions among them are the degree of independence and the technical competence of the party responsible for conducting the assessment. Table 15 outlines typical options.

Table 15. Conformity assessment options

Self-declaration by the supplier (first-party)	In-house accredited assessment body - part of the supplier's organisation (second-party)	Independent external assessment body[3] (third-party)
Supplier carries out all required controls and checks, establishes the technical documentation, ensures the conformity of the production process, and takes the risk if anything is found to be incorrect.	The body demonstrates the same technical competence and impartiality as external bodies through its accreditation. It should not undertake activities other than conformity assessment, and be independent from commercial, design and production activities.	Regulators may either designate a specific laboratory or laboratories to be used or specify eligibility criteria e.g. that they are accredited and independent from the supplier.
Pros: - Less risk of delay and costs for a product to be on the market. - Unscrupulous importers may have less incentive to attempt to bypass controls as compliance is less onerous. Cons: - Not independent and potentially not fully standardised, unless specific measurement standards and documentation are mandated. - Easier to cheat unless supported by robust market surveillance.	Pros: - The competence of the conformity assessment is assured. Cons: - Impartiality is not ensured. - Many suppliers do not operate such bodies, so it can only be one of a set of permitted options.	Pros: - The competence of the conformity assessment is assured. - Separates the interests of the assessment outcome from those of the assessor, which reduces the risk of a false performance declaration. - Possible commercial benefit (greater market acceptance and reduced risk of products held up for verification checks by MSAs) Cons: - May be more expensive and time consuming for the supplier - Insufficient capacity of verification bodies can jeopardise market transition. - Continuous verification of products placed on the market is needed to ensure ongoing compliance.

Source: [16]

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[3] There are different types of conformity assessment bodies (CABs) that can undertake conformity assessment techniques and activities. They can come in any organisational form and ownership and can be commercial in focus or not-for-profit entities. They can be government agencies, national standards bodies, trade associations, consumer organisations, or private or publicly owned companies [16]. See https://www.iso.org/sites/cascoregulators/01_3_conformity-assessment-bodies.html

7.2 Market surveillance

Market surveillance is the action of authorities checking that products in the market comply with regulations. It is comprised of monitoring, verifying (with optional risk screening), and reporting. The aim of market surveillance is to ensure that:

- products subject to energy labelling display the label with the correct information
- energy performance and related technical specifications (e.g. pertaining to electrical supply, refrigerants, etc.) are in line with the claimed performance and respect the regulations; and
- products are registered in accordance with the regulations.

Regardless of differences in approach to market surveillance, product databases serve as initial gateways for registering compliant products with regulatory authorities. The data complied within a product registration system can be used to inform decisions about whether a supplier or retailer should be the subject of conformity verification. It helps risk screening assessments, and based on this, determines which models should be sampled for verification checks. As market intelligence has commercial value, market surveillance authorities (MSAs) should limit access to this information to designated staff and their operatives and ensure adequate security systems are in place to prevent unauthorized access [18]-[21].

For each product in the product registration system, there should be information on the supplier, the model name / serial number, the country where the product was manufactured, the date the product registration was made and when it was approved, a declaration of conformity signed by the legal representative of the supplier, supporting technical documentation and test reports, the number of units that have been imported or number of units placed on the market, plus any relevant information on the compliance status of the product. For room ACs, the following technical information should be provided [2]:

1) Model name / serial number;
2) Type of unit [ductless split, self-contained, or portable];
3) Country where the product was manufactured;
4) Rated cooling (and heating, if applicable) capacity in kW;
5) Rated maximum power consumption in kW;
6) Rated performance grade;
7) Rated energy efficiency in [CSPF, APF, EER, or COP], and yearly electricity consumption in kWh;
8) Refrigerant designation in accordance with [ISO 817 or ASHRAE 34], including ODP and GWP.

This information can then be subject to fully or partially automated checks to confirm that the data is self-consistent and that the declared values respect the requirements in the regulations.

Market surveillance combines monitoring with conformity verification. A laboratory for verification testing must be independent and accredited in accordance with the ISO/International Electrotechnical Commission (IEC) 17025 standard. It should also be accredited to test specific products in accordance with energy performance test standards specified in the MEPS and energy labeling regulations. Accreditation alone may be insufficient for a test laboratory to produce consistent results with those found by other laboratories with an established track record. Government agencies must ensure the laboratory has conducted cross-testing with one or more well-respected international laboratories. Once repeatable test results are produced within an acceptable margin of error, the agency can be confident that its laboratory will yield legally enforceable test results [22].

Countries that do not have testing laboratories or need to improve existing testing facilities can consider other approaches. For example, Singapore relies on suppliers' reporting for registration. The National Energy Agency selects a random sample of registered goods for verification testing. Suppliers of the selected models provide the agency with samples for testing, which the agency seals at the warehouses. The agency engages a contractor, under a mutual recognition agreement, to collect and test the samples locally or abroad, and then it compares the verification test results against the test reports submitted by suppliers during registration. If the results are within conformance limits—generally within 10%–15% of the supplier's declared test result—the verification testing is complete [16].

Overall, the cost of testing laboratories can be mitigated via mutual recognition agreements among governments, governments and test laboratories, and test laboratories in different regions [4], [16], [23]. Global cooling equipment manufacturers often sell their products in multiple markets, and these products are often tested by laboratories accredited by national, regional, or international bodies, such as the International Laboratory Accreditation Cooperation. Authorizing the use of mutual recognition agreements to accept testing reports from non-domestic entities reduces the burden of testing on government, importers, manufacturers, and laboratories while simplifying cross-border trade [4]. Such collaboration is particularly relevant for countries with smaller economies, which are disproportionately burdened by the cost of setting up domestic laboratories.

7.3 Enforcement

Market surveillance and verification testing only deter non-compliance if the consequences of being caught are greater than the perceived benefits of circumventing the requirements. It is the role of the enforcement regime to protect the integrity of the MEPS and labelling scheme. While enforcement needs to be strong enough for genuine deterrence, it needs to be proportionate [16]. There may be considerable differences in the degree of non-conformity with MEPS and energy labelling regulations. Potential forms of non-conformity as listed in Table 16.

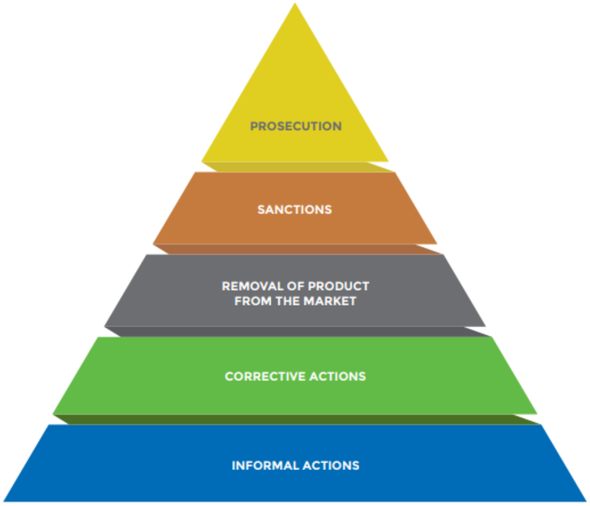
Table 16. Potential forms of non-conformity

Where	Potential cases of non-compliance
At point of import / placing on the market	• Contravention of product registration procedures • Failure to provide Conformity Assessment Report • Failure to provide requisite technical documentation • Failure to provide proof of testing • Failure to submit product for testing • Failure to cooperate with authorities • Falsified test reports • Product does not conform with MEPS requirements • Missing energy label or energy performance rating information • Inaccurate energy performance information or energy label • Smuggling products with intent to contravene regulations
At point of testing	• Failure to provide proof of testing • Failure to submit product for testing • Failure to meet performance claims or comply with MEPS • Failure to supply information to assist the testing (e.g. indicate where the product has been sold, when samples should be taken) • Falsified test reports
At point of sale	• Missing energy label or energy performance rating information • Misuse of a voluntary or mandatory energy label • Inaccurate energy performance information or energy label • Failure to provide required energy performance or labelling class in product catalogues, websites or other promotional media • Failure to meet performance claims or comply with MEPS
Following initial enforcement action	• Failure to take corrective action following initial identification of non-conformity • Failure to follow a requisite procedure • Failure to pay testing fees • Failure to pay fines • Falsely arguing that the model was already discontinued • Any or all of the above as a repeat offence after ample notice of the infraction

Source: [16]

The degree and severity of non-compliance can vary substantially as can the underlying reasons. Enforcement needs to be tailored to the situation and avoid disproportionate measures.

Enforcement authorities need flexibility in how they provide corrective action. Most follow a hierarchy of escalating actions, as shown in Figure 15. While prosecution is the ultimate potential action, most enforcement is via softer measures. These begin with notifying a party that they are in contravention of the regulations and warning them to remedy the situation. Additional corrective actions may be mandated within a certain time period. Thereafter, the product may be removed from the market. If non-compliance is deemed intentional rather than a misunderstanding, further sanctions can be applied, encompassing anything from the publicity of failure to comply, fines, suspension of the operating license, and prosecution. Enforcement authorities will need to establish the procedures they will go through under each circumstance.



Source: [24]. The bottom of the pyramid features more informal actions, and the top the most severe enforcement response to noncompliance.

Figure 15. Pyramid of escalating enforcement

Further, regulators will need to adopt a comprehensive method to evaluate energy efficiency, grid impacts, refrigerants, and climate change activities, as well as a unified set of policy rules that enable and encourage utilities to pursue combined opportunities via a single agreement with customers. For more details, we refer readers to the references and resources listed in this technical note.

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