Energy-Efficient Phasedown of HFCs: Case Study of Room Air Conditioner (RAC) Investment Opportunities in Brazil

Dr. Suely M. Carvalho, Instituto de Pesquisas Energéticas e Nucleares, (IPEN); *Mr. Márcio Ribeiro*, Instituto de Energia e Ambiente, IEE, University of São Paulo; and *Dr. Stephen O. Andersen*, Institute for Governance & Sustainable Development (IGSD)

Note: This paper, along with a PowerPoint presentation, was presented in July 2016 at a Side Event during the Resumed Session of the 37th Meeting of the Open-Ended Working Group (OEWG 37 & 38) and 3rd Extraordinary Meeting of the Parties to the Montreal Protocol, which was a pivotal moment for the Kigali HFC Phasedown Amendment and Kigali Energy Efficiency Decision, which was adopted 15 October 2016 in Rwanda.

The paper and PowerPoint presentation from the Side Event were lost from UNEP's website, so we updated our author's copy with replacement of links that had expired and with paragraph reformatting. This paper and PowerPoint were an early warning of dumping of inefficient cooling appliances with refrigerants that became obsolete with ODS phase-out that would soon be obsolete from the HFC phasedown under the Kigali Amendment. Now, ten years later, the Stop Dumping Campaign incubated by IGSD is gaining traction with shared responsibility of exporting and importing Parties to the Montreal Protocol and business opportunities for responsible cooling appliance manufacturers offering best available products in all global markets.

Originally Published September 2016; proofed and links updated November 2025 by Stephen O. Andersen (Surry, Virginia), Suely Carvalho (São Paulo, Brazil), and Márcio Ribeiro (Raleigh, North Carolina)

Abstract

This paper documents that air conditioners sold in Brazil and most other A5 Parties have far lower energy efficiency than the products sold by the same companies in developed countries (non-A5 Parties). The study is original and unique because a certification laboratory contrasts the energy performance of brands for the same size ductless mini-split room air conditioners (RACs).

Like other studies, this paper shows that the added cost of higher efficiency would be rapidly paid back to residential AC owners in lower electricity costs, and that clean air, health, and agricultural co-benefits of energy efficiency are in the national and global interest. Like other studies, this paper shows residential AC buyers are being more influenced by purchase price without proper consideration of higher ownership costs and global environmental damage avoided by higher energy efficiency.

Unlike other studies that try to encourage self-interest with labelling, this paper investigates more comprehensively the special circumstances of the Brazilian market situation and recommends: 1) accelerated top-down revision of current minimum energy performance standards (MEPS), and 2) accelerated local manufacture of inverter compressors with superior energy efficiency for lower-global warming potential (GWP) refrigerants.

In addition, this paper recommends an investment strategy for government organizations in Brazil that: 1) sets the MEPS at the level justified by electricity savings plus social co-benefits, 2) procures residential ACs on the basis of Life Cycle Climate Performance (LCCP), 3) finances the added cost in the first year for low-GWP ACs with superior energy efficiency, and 4) finances the higher cost of superior energy efficiency and low GWP in subsequent years from the savings in electricity that accrue over the life of the superior ACs.

Finally, this paper makes the case for voluntary government/industry partnerships to orchestrate the transition from ACs using high-GWP refrigerants with poor energy efficiency to superior energy efficiency ACs using lower-GWP refrigerants.

Table of Contents

Figures

Introduction

With some exceptions[1], by 2016 the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) had already phased out the production and consumption of hydrochlorofluorocarbons (HCFCs)[2] in developed countries (classified under the Montreal Protocol as "non-Article 5 Parties" and abbreviated as "non-A5 Parties") and has begun the HCFC phase out in developing countries (A5 Parties). In compliance with the Montreal Protocol, most non-A5 Parties replaced ozone-depleting HCFC-22 used in air conditioners (ACs) and refrigeration applications and in foam blowing applications with ozone-safe hydrofluorocarbons (HFCs).[3] In the case of residential ACs, the overwhelming choice until recently was HFC-410A, which is a 50%/50% blend of HFC-32 and HFC-125. The typical classification of vapor compression residential AC equipment using refrigerants includes: 1) portable, 2) window, 3) ductless mini-split, and 4) central ducted (*see* Figure 1).

Figure 1. Types of air conditioners. Source: The Engineers Post, n.d.

[1] The Montreal Protocol does not control use of HCFCs for feedstock or process agent applications and allows a period of continuing use for service of air conditioning and refrigeration equipment once use in new products is halted.

[2] The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), in document ANSI/ASHRAE 34-2022: Designation and Safety Classification of Refrigerants, lists approved refrigerant numbers and assigns safety classifications based on toxicity and flammability data. For example, CFC-11 (trichlorofluoromethane) is assigned the shorthand number R-11.

[3] The Montreal Protocol has unique control schedules for each "group" of chemical substances, with faster reductions for non-A5 Parties to stimulate technical innovation and then reduction in A5 Parties once technology is commercialized and competitive. Within each chemical group, each Party chooses a combination of actions to reduce consumption and production by the specified "ODP-weighted" amount. The potency of a chemical substance in depleting stratospheric ozone over its atmospheric life is expressed as "ozone depletion potential" (ODP) relative to the reference chemical CFC-11, which is set equal to 1. The potency of a chemical substance in forcing climate change over a specified time period (typically 100 years) is expressed as GWP relative to the reference chemical carbon dioxide (CO_2), which is set equal to 1. This means that the emission of one kilogram of CFC-12 causes as much climate forcing as 10,200 kg of CO_2 because the $GWP_{100\text{-}yr}$ of CFC-12 is 10,200.

Portable and window ACs have the lowest energy efficiency; central AC can be efficient in generating cold air at the evaporator, but overall is inefficient as a consequence of cooling unoccupied rooms and duct energy loss; and ductless mini-split have the highest energy efficiency with the easy ability to cool only occupied rooms and to direct the cool air to the portion of the room where people are located. The latest technology has self-cleaning evaporators, self-adjusting temperature and humidity to give the desired level of comfort at the lowest carbon footprint, and notification when the air filter or condenser coils need cleaning.

High global warming potential (GWP)[4] HFCs that were once necessary to rapidly replace ozone-depleting substances (ODSs) in applications where environmentally superior alternatives are now available are now technically obsolete and increasingly subject to national regulation and global controls. Regulations in the Australia, Canada, European Union (EU), Japan, and the United States (US) are phasing out HFC-134a in stationary and mobile ACs and creating incentives for environmentally superior alternatives; the Kyoto Protocol is attempting to control HFC emissions; and the phasedown of production and consumption of HFCs will soon begin under an anticipated amendment to the Montreal Protocol. Similar actions are underway to remove other HFCs from the lists of allowed uses in specific applications, including room AC. Finally, citizens and private corporations are organizing to boycott and avoid HFCs.

A5 Parties still using HCFC-22 in residential ACs can leapfrog high-GWP HFC-410A and select next-generation refrigerants based on technical and environmental performance. Furthermore, both A5 and non-A5 Parties can choose to simultaneously upgrade residential ACs to next-generation refrigerants and superior energy efficiency at the same time at a combined lower cost than undertaking the transitions separately. Best of all, the Montreal Protocol Multilateral Fund for the Implementation of the Montreal Protocol (MLF) can finance the agreed incremental cost of this simultaneous transition, if instructed by Parties in the Amendment text.

Demand for AC Is Growing Rapidly in Populous Countries with Increasing Incomes

Figure 2 graphically presents cooling degree days (CDD),[5] with the relative size of the bubble reflecting the population, and the CDD measured on the X-axis. Air conditioning use depends on access to electricity and electricity price, ambient outside temperature, architecture, and household incomes. In hot and humid countries with low market penetration of room ACs, the sales and use of air conditioning is poised to increase dramatically (Zaelke et al. 2016; Shah et al. 2015; Phadke et al. 2014; Rajadhyaksha

[4] Global Warming Potential is a metric that compares the warming effect over a specified time period of greenhouse gases to that of carbon dioxide (CO_2), which is assigned a GWP of 1. Estimates of GWP depend on the precision of laboratory experiments and on the global warming from the reference chemical CO_2 that changes over time as carbon sinks are saturated. The most respected reference sources for GWP are the Montreal Protocol Scientific Assessment (SAP) Quadrennial Report (latest 2022) and the Intergovernmental Panel on Climate Change (IPCC) periodic Assessment Reports; latest 2023 AR6). However, treaty controls and national regulations typically fix the GWP at the values in a specific report and usually for a 100-year time period. This paper lists 100-yr GWPs from the 2007 IPCC AR4.

[5] Cooling Degree Day (CDD) is a metric intended to measure the demand for cooling derived from measurements of outside air temperature, with the cooling requirements presumed to be directly proportional to the number of CDD at any given location. It is calculated by subtracting an outside temperature considered comfortable (typically 65° Fahrenheit/18° Celsius in developed countries) from a day's average temperature.

2013). In locations experiencing global warming, AC use is expected to increase proportionally to CDD; however, income growth by itself explains most of the increase (Davis and Gertler, 2015). Furthermore, air conditioning use will be higher in very hot climates with modern industrial jobs that require even low-income workers to be well-rested and alert (Andersen and Zhang, unpublished).

Consider that Brazil has two-thirds the population of the United States but 2.5 times as many CDDs, which indicates that Brazil will consume more than twice the energy in cooling once incomes allow (Davis and Gertler 2015).

India, Southeast Asia, and Brazil all have high CDDs, with room AC sales growing at ~10–15%/year in India, and at ~20%/year in Brazil (Shah et al. 2013).

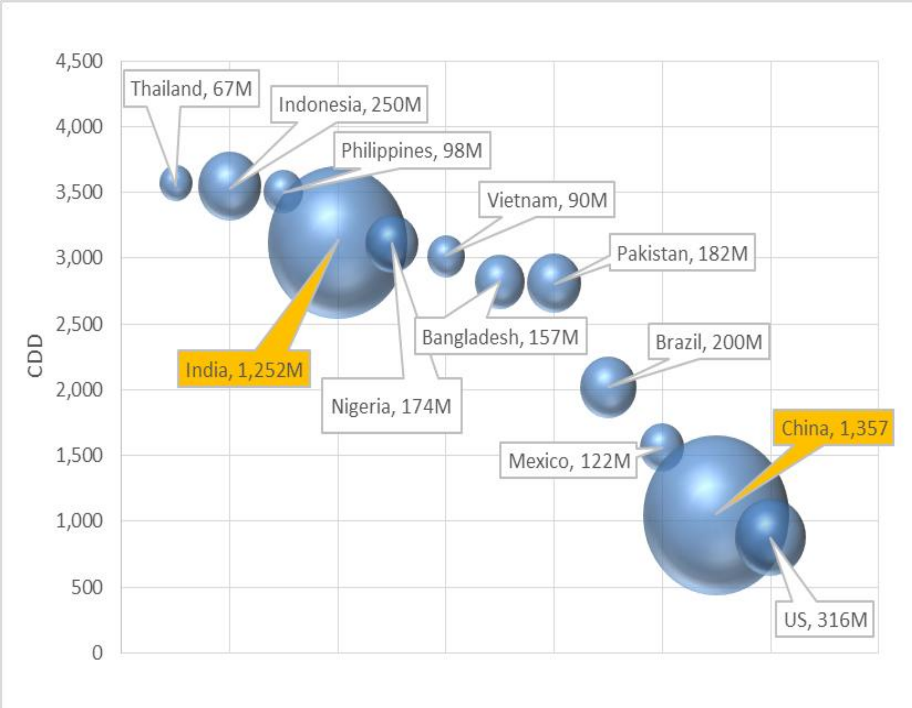

Figure 2. Cooling Degree Days for populous developing countries and the United States of America. Source: Davis and Gertler 2015

Buyers Are Cheating Themselves with Low Efficiency

Almost everywhere in the world, purchasers of new room ACs make the expensive mistake of looking for the lowest priced model large enough to cool the room. This ignores the fact that the added cost of premium energy performance is quickly paid back in electricity savings, and that energy-efficient models typically have higher quality components that last longer without expensive service or unrepairable product failure. Worse still, the buyers of low-cost ACs are causing unnecessary air pollution that increases the cost of health care and damages agricultural crops and natural ecosystems. The simple math is that a low-cost AC is “penny wise and pound foolish” when you consider that everyone pays more for electricity, health care, and food.

For example, Figure 3 shows the simple payback of the added cost of superior energy efficiency of room air conditioners (RACs) sold in India where some of the best analyses of the private and public co-benefits has been undertaken (Zaelke et al. 2016; Shah et al.

2015; Phadke et al. 2013; NRDC 2013). With the most reasonable cost estimates indicated by the green line, the payback time is just three years to double the energy efficiency and cut the annual electricity operating cost in half! Where else can you earn 33% per year on an investment with payback in three years and savings you can spend on other purchases after the first three years of ownership.

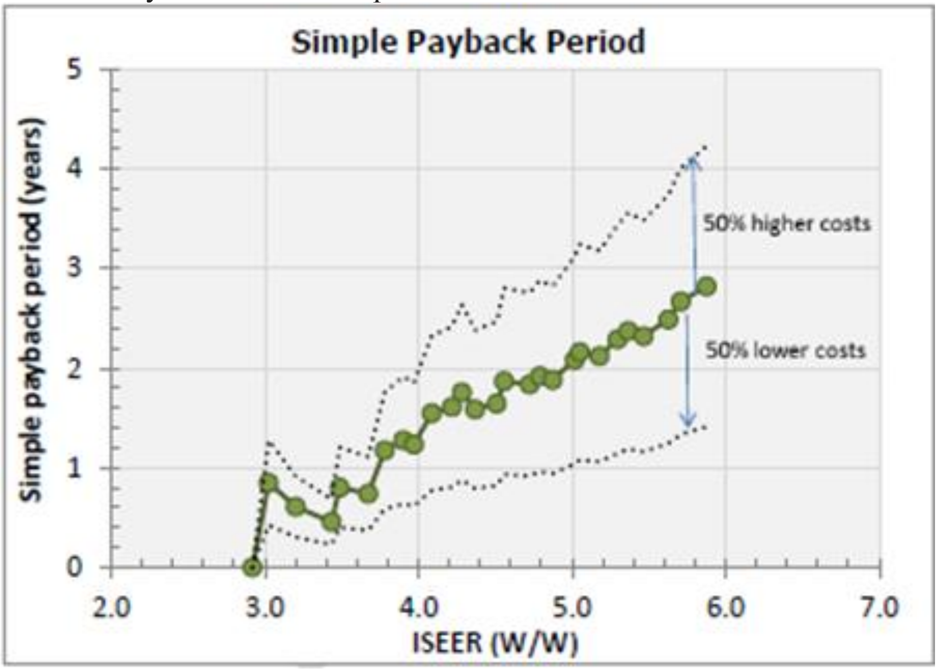

Figure 3. Fast payback on small added cost of superior energy efficiency. Source: Shah et al. 2016; ISEER = India Seasonal Energy Efficiency Ratio; W/W = watts per watt

Some Countries Demand—and Get—High Energy Efficiency!

China, Japan, and Korea have put in place regulations that encourage and reward high energy efficiency and have commercialized RACs with superior energy efficiency of greater than 6.0 Watts cooling per Watt electricity (W/W). In contrast, Brazil currently requires a minimum energy efficiency of just 2.6 W/W, which results in average efficiency of ACs of around 3.0 W/W—half the potential energy efficiency.

Our investigation determined that manufacturers of residential ACs have been unable to offer superior energy efficiency due to lack of energy-efficient compressors and that these manufacturers have been uncertain that customers would embrace the slightly higher cost of superior energy efficiency, even if electricity savings quickly pay back the higher cost.

Cooling Has a Significant Impact on Peak Electricity Load and Quality of Life

Electric utilities have the ambition to build enough generating capacity to serve whatever demand results from economic development, population growth, and tastes and preferences of citizens. Until climate change threatened the planet's economic, social, and natural systems, most economists viewed energy supply as a challenge of scarce unrenewable fossil-fuel resources and prohibitively expensive renewable energy resources such as wind, solar, and biomass. Now it is clear that there is more than enough fossil fuel available at low cost to destroy the atmosphere and life on earth. It also is clear that renewable solar and wind energy is available at lower costs than previously anticipated, particularly when the health and agricultural damage is included in the calculation. The challenge is to replace fossil fuel with renewable power sources and to increase energy efficiency fast enough to avoid cost impacts, particularly on citizens emerging from poverty.

In countries with long, hot, and humid cooling seasons, a significant portion of the total summer peak electric load in relatively wealthy metropolitan cities is consumed for air conditioning.

Figure *4* graphically shows that in India, air conditioning reaches 40-60% of peak load.

Brazil has 4,564 power generation plants in operation with a total of 147,650,249 kW of installed capacity. In the next few years, an additional 8,825,883 kW of generation capacity is expected from investment by 214 enterprises with power plants currently under construction. Thermoelectric will comprise 19.4% of total generating power, mostly from coal but with some biomass. There are also 671 power plants planned but with construction not started yet. From this total, 163 plants will be thermoelectric, representing 39.2% of the total generating power.[6]

For Brazil, it is calculated that between 31 and 72 500-megawatt (MW) power plants can be avoided by application of technically feasible increases in energy efficiency when companies choose energy-efficient, low-GWP refrigerants to replace HCFC-22 and HFC-410A (Shah et al. 2015).

Energy efficiency becomes even more critical when considering the role of fossil-fuel power plants in meeting new electricity demand.

Enlightened electric utility management considers not only the high carbon intensity of thermoelectric plants but also the substantial economic burden they impose on the country. Avoiding the need for even a single plant of this size through energy efficiency represents hundreds of millions of dollars in avoided public and private spending.
In addition to capital investments, the operating costs of thermoelectric plants, largely driven by imported fuel, represent a continuous outflow of national resources. Redirecting these expenditures toward energy-efficiency programs would stimulate local economic activity by keeping financial resources circulating in the national economy rather than sending them overseas to pay for imported fuel and plant components.

For these reasons, energy efficiency is not only a climate-mitigation tool but also a strategic economic lever. By reducing demand growth, energy efficiency avoids the need for new thermoelectric power plants, saves significant construction and fuel costs, and enables the reinvestment of these savings into local communities, infrastructure, and sustainable economic development.

[6] Agência Nacioal de Energia Elétrica (ANEEL) information archived at https://web.archive.org/web/20160613222306/https://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm.

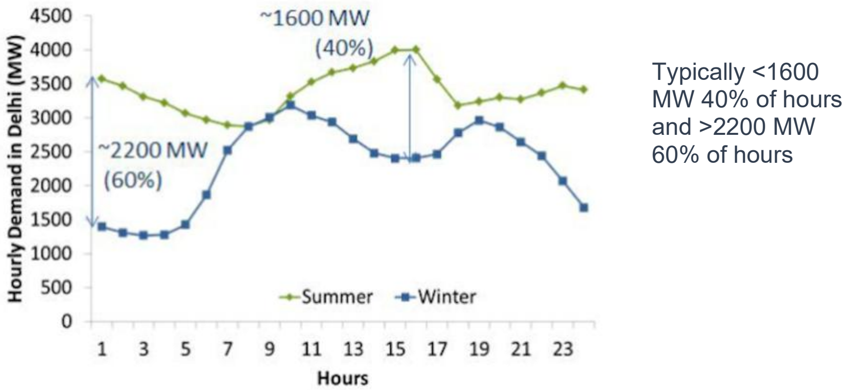

Figure 4. Summer and winter peak electric load, Delhi, India. Source: DSLDC 2013

Recent HCFC-22 and HFC-410A AC Technology

From the 1950s until about 1996, all residential ACs used HCFC-22, which has an ozone depletion potential (ODP) of 0.02 and a global warming potential ($GWP_{(IPCC\ AR4\ 100\text{-}yr)}$ of 1810); it depletes the stratospheric ozone layer and is a powerful greenhouse gas (GHG). In 1991, Allied Signal (now Honeywell) patented HFC-410A (ODP=0; $GWP_{(IPCC\ AR4\ 100\text{-}yr)}$ =2088), which is a 50%/50% mixture by weight of HFC-32 (ODP=0; $GWP_{(IPCC\ AR4\ 100\text{-}yr)}$ =675) and HFC-125 (ODP=0; $GWP_{(IPCC\ AR4\ 100\text{-}yr)}$ =3500), and in 1996 Carrier Corporation was the first company to commercialize an HFC-410A-based residential air conditioning system. From 1996 in non-A5 Parties and from about 2010 in A5 Parties, the transition away from HCFC-22 to HFC-410A began. The Honeywell application patent for HFC-410A expired in 2011 in most jurisdictions.

Next-Generation AC Refrigerants

HCFC-22 and HFC-410A are obsolete and unsustainable refrigerants that will be in short supply and increasingly costly in the future. Technology based on these obsolete refrigerants will be unsupported by manufacturers, and parts will be hard to find. Informed buyers will want to choose next-generation technology that achieves superior energy efficiency with lower GWP.

Examples of energy-efficient lower-GWP alternatives for room ACs are:

1. *HC-290* (propane) (ozone-safe; $GWP_{100\text{-}yr}<3$; ASHRAE flammability 3 – highly flammable) is the clear first choice where the refrigerant charge necessary to achieve energy-efficient cooling would be safe if accidently discharged into the room as a result of a leak. HC-290 ACs can typically achieve up to 1.5 tons cooling capacity with a separation of <3 meters between the indoor evaporator and outdoor condenser units and up to 1.0 tonnes cooling capacity when separation of indoor and outdoor units is greater than about 3 meters, with a larger portion of allowable refrigerant charge contained in longer tubes.[7] HC-290 is very low in cost, not

[7] The calculation of indicative safe cooling capacity is estimated by the authors and is not precise. The actual safe capacity depends on the size of the room, the sources of ignition, and the volume of refrigerant in the tubes connecting the evaporator and condenser. The volume of the tubes is determined by the inside diameter and length.

protected by process or application patents, and slowly gaining market penetration in China and India, but due to pending safety review and appropriate regulation is in few other markets. It is noteworthy that HC-290 is not yet considered safe according to existing safety standards in many of the countries advocating its use in A5 Parties.

2. *HFC-32* (ozone-safe; $GWP_{(IPCC\ AR4\ 100\text{-}yr)}$ = 675, but with 30% reduced refrigerant charge; ASHRAE flammability 2L – lower flammability and risk) is a clear choice for ACs too large to safely use HC-290, with high cooling capacity and energy efficiency even at high ambient temperature and humidity (HAT) (Zeiger et al. 2014). Daikin Corporation has released the application patents for free global use of HF-290.
3. *R-452B* (ozone-safe; $GWP_{100\text{-}yr}$~675; ASHRAE flammability 2L – lower flammability and risk) is a blend of 26% hydrofluoroolefin (HFO)-1234yf, 7% HFC-125, and 67% HFC-32). Ingersoll Rand has announced that they will make their patents available on a royalty-free basis for the application of R-452B in heating, ventilating, and air conditioning (HVAC) equipment[8], however Chemours has not yet released patents, which may restrict use.

A large variety of lower-GWP alternatives are being tested at different ambient temperatures, including high and extreme temperatures, such as 52 and 55 degrees Celsius. Some alternatives tested in soft-optimized units[9] showed similar or better performance than the refrigerants being replaced.

The Climate Impact of Acs, and the LCCP Metric

The issue of global warming is becoming increasingly important. Global warming occurs because some gases released into the atmosphere are more transparent to incoming solar energy than to thermal radiation emitted by the earth's surface (IPCC 2013). The continuous trapping of the thermal infrared radiation from the earth (i.e., like glass trapping heat in a greenhouse) increases the earth's surface temperature and forces climatic change. Climate change has a wide range of unacceptable consequences including higher temperatures; melting glaciers; rising seas; changing landscapes; increased risk of drought, fire, and floods; more heat-related illness; the spread of diseases; and economic losses, especially related to agriculture (IPCC 2014).

The climate impact of ACs is a combination of 1) direct refrigerant GHG emissions from equipment leaks and servicing; 2) indirect emissions from electricity necessary to power the AC; and 3) embodied carbon emissions from production, service, and dismantling/recycling at the end of product life. Life Cycle Climate Performance (LCCP) is an analytical technique that accounts for all three categories of heat-trapping emissions (Papasavva et al. 2010). For AC applications, LCCP is calculated according to published LCCP guidelines, standards, and tools from the Air-Conditioning, Heating, and Refrigeration Technology Institute (AHRTI), International Institute of Refrigeration

[8] Ingersoll Rand Press release, 2015, http://company.ingersollrand.com/content/dam/ir-corp/documents/pdf/2016-DR55-Update-Release-FINAL.pdf.

[9] Soft-optimized units are production units that have undergone modifications such as refrigerant charge optimization, lubricant change, and flow control device changes to run with a different refrigerant. This is in contrast with fully optimized units, which are purpose-built for a refrigerant.

(IIR), Oak Ridge National Laboratory (ORNL), and the Technical University of Denmark Institute of Product Development (IPU) (AHRTI 2011; IIR 2016; IPU 2016).

Some refrigerants (HFC-134a, HFC-227ea, HFC-365mfc, HFC-236fa, HFO-1234yf, and HFO-1234ze(E)) have environmental impacts from atmospheric degradation products, including carbonyl fluoride (COF_2), formyl fluoride (HCOF), hydrogen fluoride (HF), and trifluoroacetic acid (TFA) (Papasavva and Moomaw 2014). Refrigerants ammonia (R-717), carbon dioxide (CO_2 – R-744), hydrocarbons (Methane R-50, Ethane R-170, Propane R-290, Butane R-600, Isobutane R-600a, Ethylene R-1150, and Propylene R-1270), HFC-32, and HFC-152a create no worrisome atmospheric degradation products, but hydrocarbons are volatile organic compounds (VOCs) that degrade local air quality with human and animal health implications and damage agricultural crops and natural ecosystems.

Contribution of Refrigerant, Equipment, Installation, and Operating Costs

Although the direct contribution of future emissions of HFCs to climate change is projected to be huge, it is dwarfed by the greenhouse gas contribution from burning fossil fuels to generate electricity for those appliances. The relative contribution depends on the carbon intensity of the electricity, the electricity transmission losses, the climate, and the cooling preferences of air conditioner owners.

The US Department of Energy (DOE) Oak Ridge National Laboratory (ORNL) and Navigant Consulting recently determined that the cost of HCFC-22 and HFC-410A refrigerants is typically less than one percent of life cycle costs of the AC system in almost every case—from India to the USA—with larger cost portions for electricity in locations having long, hot, and humid cooling seasons (Goetzer et al. 2016). One important message from this study is that superior energy efficiency mitigates potential increases in new refrigerant costs because the electricity savings is far greater than the increase in refrigerant cost.

The Brazil Case for Rapid Phasedown of High-GWP HFCs with Simultaneous Increase in MEPS

Brazil has had legal mechanisms in place since 2001 that can be immediately strengthened to achieve climate protection and increase Brazilian prosperity. In 2007, Brazil approved a specific regulation on ACs, setting MEPS. In 2011, the 2007 MEPS was strengthened; however, the minimum level established in the Brazilian regulations is far from that practiced in most other countries. For example, with successful energy efficiency actions in the residential air conditioning sector, China, the EU, the Republic of Korea, and Japan sell equipment with much higher efficiency than the best available in Brazil. Brazil is the fifth largest market for window and split ACs in the world (*see* Figure 5).

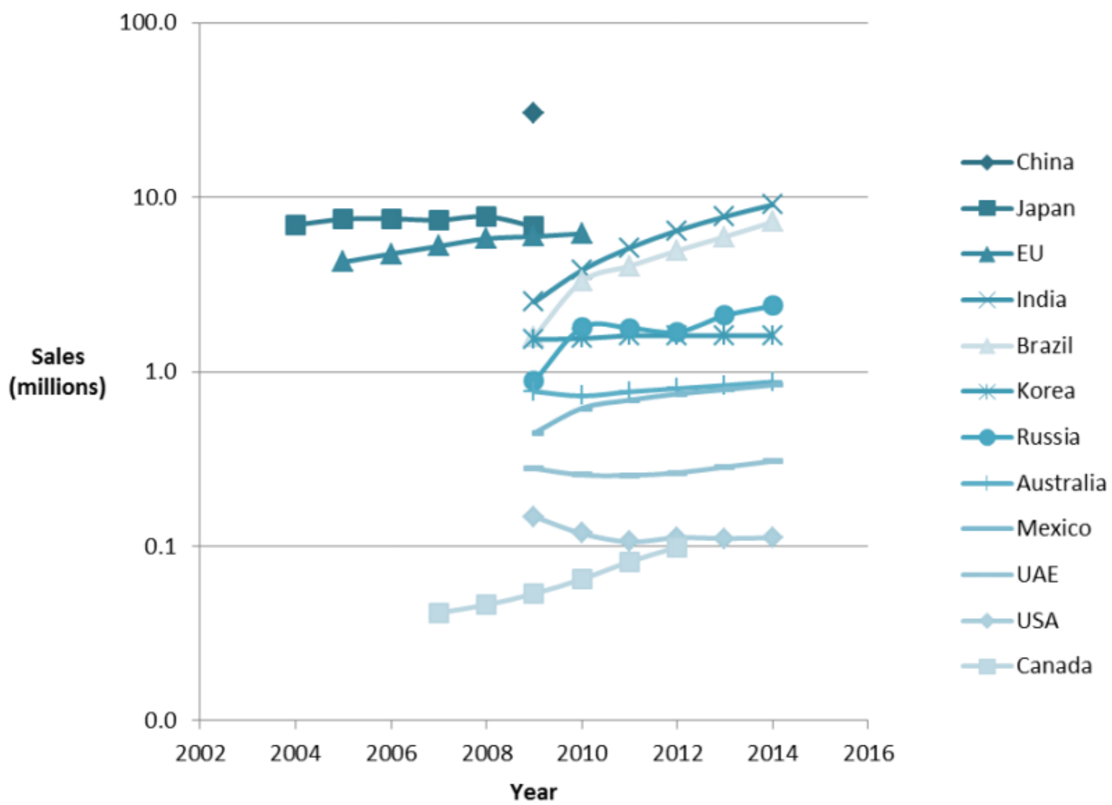

Figure 5. Sales of RACs in various countries from 2002–2014.
Source: Shah, Phadke, and Wade 2013

According to a study by the US DOE's Lawrence Berkeley National Laboratory (LBNL), the peak gigawatts (GW) load reduction in 2030 from a 30% improvement in efficiency added to the use of lower-GWP refrigerants would avoid, in terms of generation capacity in Brazil, the equivalent of 31–72 power plants of 500 MW. Efficiency improvement alone (determined under ISO 5151 T1 test conditions) would avoid 14–32 power plants of 500 MW each (Shah et al. 2015). Refrigerant transition impact will depend on the refrigerant choice, but energy efficiency will be the main driver. Improved energy efficiency together with the lower-GWP refrigerant choice will offer the best result regarding overall climate benefit.

The Brazilian RAC energy efficiency labelling programme has four classes of products, A through D,[10] as in

Table 1 below:

Table 1. Brazilian labelling programme

[10] NBR 5151: Methodology AHRI –A; Test temperature 19°C (room), 27°C (ambient). ACs with inverters are tested on the same apparatus as ACs without inverters.

Label Class	Minimum Efficiency (W/W)	Maximum Efficiency (W/W)
A	>3.23	n.a.
B	3.02	3.23
C	2.81	3.02
D	2.60	2.81

From 16 August 2014, the energy efficiency ratio (EER) A Class split AC MEPS is 3.23 W/W and 2.6 W/W for class D, which is incredibly inefficient, damaging to climate, and costly to AC owners. These numbers do not consider the lower direct climate impact of refrigerant emissions. China has ACs with values greater than 6.0 W/W, and in Japan this ratio exceeds 6.5 W/W[11].

The Brazil National Institute of Metrology, Quality, and Technology (INMETRO),[12] in a test of 2,084 window and split ACs sold in Brazil, determined that the average EER is only 2.9 W/W, with a sample of 782 split ACs averaging 2.87 W/W. The most energy efficient was the split high wall type, which averaged 3.04 W/W in a separate study (1302 units tested).

The data from INMETRO[13] also indicates that the highest efficiency of room AC equipment labelled in Brazil is only 4.79 W/W; however, a market survey determined that ACs with efficiency greater than 4 W/W are not available for purchase in the Brazilian market. This shows that next-generation products can be up to two times more energy efficient than the average products sold today (*see* Figure 6).

[11] 2015 INMETRO Tabela de E Energética archived at https://web.archive.org/web/20151115192112/http://www.inmetro.gov.br/consumidor/tabelas.asp. Extracted from technical note on minimal levels of energy efficiency of air conditioners in Brazil, Cláudia Donald Pereira, Roberto Lamberts e Enedir Ghisi. Centro Brasileiro de Eficiência Energética em Edificações", cb3e.ufsc.br. July 2013.
[12] 2014 INMETRO data archived at https://web.archive.org/web/*/http://www.inmetro.gov.br/consumidor/pbe/condicionadores_ar*.
[13] 2014 INMETRO PROCEL data archived at https://web.archive.org/web/20201202031727/https://pdf.webarcondicionado.com.br/tabela-procel/2014/tp-ar-condicionado-split-hi-wall-2014.pdf.

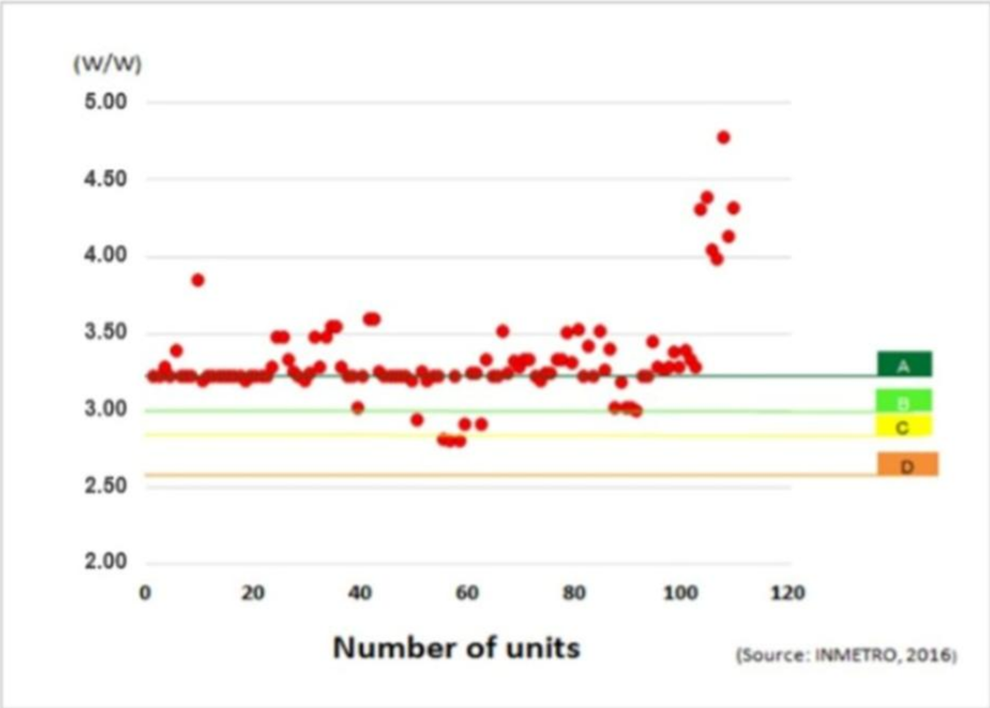

Figure 6. Split Hi-wall AC models tested in Brazil[14]. Source: INMETRO 2016

It is significant that the efficiency offered in Brazil is lower than would be in the consumer and public interest based on energy savings and social cost, respectively. It is also significant that at most efficiency levels, ACs can be purchased at a wide range of prices. For example, ACs clustering around the minimum MEPS necessary to qualify for an "A" label can be purchased for as little as US$300 or as much as US$500 as in Figure 7.

[14] All brands: 9000, 12000 and 18000 BTU cooling capacity.

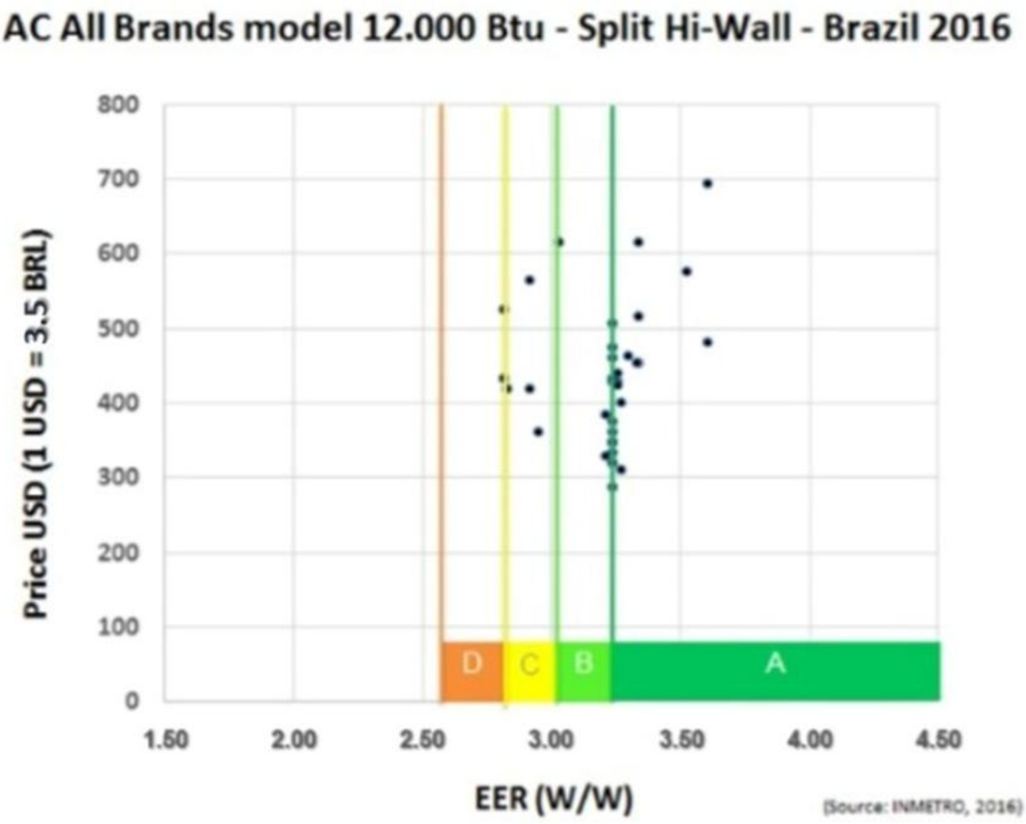

Figure 7. EER versus costs of hi-wall split AC. Source: INMETRO 2016.

AC systems in Brazil could have energy efficiency up to 5.67 W/W and still maintain the cost-benefit value for the final consumer (Shah, Phadke, and Waide 2013). The barriers to increase beyond this value will be market/cost related, not technological.

Superior Efficiency using Lower-GWP Refrigerants

The path forward to superior energy efficiency includes three simultaneous actions:

1. Strengthening of MEPS and labelling program
2. Negotiating affordable prices for superior energy efficiency
3. Avoiding "sticker shock" as consumers are required to pay more for ACs that pay them back quickly in energy savings

The first challenge is to decide how much AC price increase can be borne by consumers and how much should be paid by national and international stakeholders. This is not as complicated as it looks because the higher price is so quickly paid back in energy savings and because it is relatively easy to implement a finance scheme such that an AC buyer sees nothing but savings.

Consider the example of a 6.0 W/W split AC that cost US$200 more than a typical 3.2 W/W unit with a two-year payback of the added cost from electric savings and a product life of 10 years. The customer could be offered the 6.0 W/W product for the same price as the inefficient model, with the electric utility financing the added cost to be paid back during the cooling season based on a simple formula. In this way, every monthly electric bill would be less than if the inefficient product were owned. The unpaid balance would earn reasonable interest for the electric utility until paid in full, when all electricity savings would henceforth be enjoyed by the customer. Under this plan, in every month, the consumer is better off, the electric utility earns income on the investment and avoids expensive power plants and fuel, and society enjoys cleaner air and lower GHG emissions.

The second challenge is that in Brazil, no one currently manufactures the inverter compressor components that are necessary for superior efficiency. The Brazil domestic content law requires that 80% of AC costs be nationally sourced, and the room AC compressor itself represents more than the 20% that can be imported. Catch 22. The solution is to motivate a manufacturer to make compressors locally or to exempt the compressor from the domestic content law.

The devil in the detail is that any such effort needs high-level policy support. Fortunately, that is already underway in a Brazilian Air Conditioning, Heating, and Ventilation Association (ABRAVA) proposal, and Brazil is ready to act as described in the next section.

The ABRAVA Proposal

In early 2016, industry and civic leaders under the authority of the Board of Directors of ABRAVA completed a consultation process that crafted the way forward. ABRAVA sent that road map to the Brazil Minister of Energy requesting:

> *Revision of the Brazilian Basic Production Process to enable development of components allowing superior efficiency (e.g., inverter compressors).*
>
> *Revision of the Brazilian Buildings Programme ("PBE Edifica") expanding labelling to guarantee buildings are constructed and operated efficiently.*

Together, these two actions set the stage for the Brazilian applications for funding by the Montreal Protocol financial mechanism, the Multilateral Fund (MLF), as soon as the Montreal Protocol HFC Phasedown Amendment is agreed, which is bound to happen before end of 2016 at the Meeting of the Parties (MOP) in Kigali, Rwanda 10–14 October.

Brazil can be part of early actions to protect the climate and to prevent AC buyers from cheating themselves with low-efficiency products.

Glossary of Unique Technical Terms

Coefficient of Performance (COP) in cooling is a measure of how effectively a system removes heat from a cold space relative to the amount of work (energy) required; essentially how much cooling is achieved for each unit of energy input. The higher the COP, the more efficient the system. COP = heat removed (e. g., joules, watts) / power input (e. g., joules, watts).

Energy Efficiency Ratio (EER) is a measure of efficiency of a system at peak load capacity. The Integrated Energy Efficiency Ratio (IEER) was recently developed to address the actual efficiency of HVAC equipment that operates at different load levels. This ratio accounts for both full load and part load efficiencies by weighting EER values at different load capacities and adding them together based on the approximate number of hours a unit spends at each load point throughout its life.

Acronyms

ABRAVA	Air Conditioning, Heating, and Ventilation Association (Brazil)
AC	air conditioner
AHRTI	Air-Conditioning, Heating, and Refrigeration Technology Institute
ASHRAE	American Society of Heating Refrigeration and Air-Conditioning Engineers
ANEEL	Agência Nacional de Energia Elétrica (Brazil)
CCAC	Climate and Clean Air Coalition (UNEP)
CDD	cooling degree days
CH_4	methane
CO_2	carbon dioxide
COF_2	carbonyl fluoride
DOE	Department of Energy (US)
EER	energy efficiency ratio
EU	European Union
GHG	greenhouse ga
GW	gigawatts
GWP	global warming potential
HAT	high ambient temperature
HC	hydrocarbon
HCOF	formyl fluoride
HF	hydrogen fluoride
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin
HVAC	heating, ventilating, and air conditioning
IGSD	Institute for Governance & Sustainable Development
IIR	International Institute of Refrigeration
INMETRO	National Institute of Metrology, Quality and Technology (Brazil)
IPCC	Intergovernmental Panel on Climate Change
IPEN	Instituto de Pesquisas Energéticas e Nucleares,
IPU	Institute of Product Development (Technical University of Denmark)
ISEER	Indian Seasonal Energy Efficiency Ratio
kW	kilowatt
LBNL	Lawrence Berkeley National Laboratory
LCCP	life cycle climate performance
MEPS	minimum energy performance standard
MLF	Multilateral Fund (for the Implementation of the Montreal Protocol)
MOP	Meeting of the Parties (to the Montreal Protocol
NRDC	Natural Resources Defense Council
ODP	ozone-depleting potential
ODS	ozone-depleting substance
ORNL	Oak Ridge National Laboratory

RAC	room air conditioner
SEER	Seasonal Energy Efficiency Ratio
SLCP	short-lived climate pollutants[15]
TFA	trifluoroacetic acid
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
VOC	volatile organic compound
W/W	Watt per Watt

Bibliography

- AHRTI (Air-Conditioning, Heating, and Refrigeration Institute). 2011. *Life Cycle Climate Performance Model for Residential Heat Pump Systems*, Report No. 09003-01. https://www.ahrinet.org/system/files/2023-08/AHRTI-Rpt-09003-01.pdf.
- Davis; Lucas W., and Paul J. Gertler. 2015. Contribution of Air Conditioning Adoption to Future Energy Use Under Global Warming. *Proceedings of the National Academy of Sciences* (PNAS) 112(19): 5962–5967. https://doi.org/10.1073/pnas.1423558112.
- DSLDC (Delhi State Load Dispatch Centre). 2012. Hourly Demand Data from the State Load Dispatch Centre.
- Goetzler, William, Matt Guernsey, Jim Young, Jay Fuhrman, and Omar Abdelaziz. 2016. *The Future of Air Conditioning for Buildings,* No. DOE/EE-1394. Oak Ridge National Laboratory, Oak Ridge TN. https://www.energy.gov/sites/prod/files/2016/07/f33/The%20Future%20of%20AC%20Report%20-%20Full%20Report_0.pdf.
- IIR (International Institute of Refrigeration). 2016. Guideline for Life Cycle Climate Performance, v.1.2. https://iifiir.org/en/fridoc/guideline-for-life-cycle-climate-performance-lccp-calculation-tool-145241.
- INMETRO (Instituto Nacional de Metrologia, Qualidade e Tecnologia). 2016. https://www.gov.br/inmetro/pt-br. (Note: source data for the figures may not be available online at this time.)
- Intergovernmental Panel on Climate Change (IPCC). 2013. *Climate Change 2013: The Physical Science Basis (Fifth Assessment Report (AR5))*. p. 126. http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter01_FINAL.pdf. https://www.ipcc.ch/site/assets/uploads/2017/09/WG1AR5_Chapter01_FINAL.pdf
- Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability,* pp 13–25. http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf.
- IPU (Instituttet for Produktudvikling). 2016. Pack Calculation Pro. https://web.archive.org/web/20160209030450/http://www.en.ipu.dk/Indhold/refrigeration-and-energy-technology/Pack%20Calculation%20Pro/Pack%20Calculation%20Pro.aspx.
- Natural Resources Defense Council (NRDC). 2013. *Cooling India with Less Warming: The Business Case for Phasing Down HFCs in Room and Vehicle Air Conditioning*, Issue Paper IB: 13-04-A. https://www.nrdc.org/sites/default/files/air-conditioner-efficiency-IP.pdf.
- Papasavva, Stella, William R. Hill, and Stephen O. Andersen. 2010. GREEN-MAC-LCCP: A Tool for Assessing the Life Cycle Climate Performance of MAC Systems. *Environmental Science & Technology* 44(19): 7666–7672. https://doi.org/10.1021/es100849g.

[15] Short-lived climate pollutants (SLCPs) are powerful climate forcers that remain in the atmosphere for a much shorter period of time than GHGs such as CO_2. SLCPs include black carbon, methane (CH_4), tropospheric ozone, and HFCs.

- Papasavva, Stella, and William Moomaw. 2014. *Comparison between HFC-134a and Alternative Refrigerants in Mobile Air Conditioners using the GREEN MAC-LCCP© Model*. 15th International Refrigeration and Air Conditioning Conference, 14–17 July, Purdue University, Purdue e-Pubs. http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2474&context=iracc.
- Phadke, Amol, Nikit Adhyankar, and Nihar Shah. 2013. *Avoiding 100 New Power Plants by Increasing Efficiency of Room Air Conditioners in India: Opportunities and Challenges*. No. LBNL-6674E. Lawrence Berkeley National Laboratory, pp. 16–17, Table 4 ("We estimate that about 30% of the urban households are likely to own a room air conditioner by 2020 and about 73% are likely to own a room air conditioner by 2030."). https://eta-publications.lbl.gov/sites/default/files/lbnl-6674e.pdf
- Rajadhyaksha, Dilip. 2013. Development and Handling of Hydrocarbon Air-Conditioners – The Godrej Experience (Godrej & Boyce Mfg. Co. Ltd presentation at Bangkok Technology Conference, 29 June 2013). https://climate.ec.europa.eu/system/files/2016-11/rajadhyaska_en.pdf.
- Shah, Nihar, Ma Wei, Virginie Letschert, Amol Phadke, et al. 2015. Energy efficiency potential in refrigeration systems: Avoided power plants in Brazil. Personal communication.
- Shah, Nihar, Max Wei, Virginie Letschert, and Amol Phadke. 2015. *Benefits Of Leapfrogging to Super-Efficiency and Low Global Warming Potential Refrigerants in Air Conditioning*, No. LBNL-1003671. Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/lbnl-1003671.pdf.
- Shah, Nihar, Nikit Abhyankar, Won Young Park, and Amol Phadke. 2016. *Cost-Benefit of Improving the Efficiency of Room Air Conditioners (Inverter and Fixed Speed) in India*, No. LBNL-1005787, Lawrence Berkeley National Laboratory. https://www.osti.gov/servlets/purl/1342227.
- Shah, Nihar, Amol Phadke, and Paul Waide. 2013. *Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners*. Environmental Energy Technologies Division, International Energy Studies Group, Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/lbnl-6164e.pdf.
- The Engineers Post. n.d. Online. https://www.theengineerspost.com/?s=air+conditioner
- Zaelke, Durwood, Nathan Borgford-Parnell, and Stephen O. Andersen. 2015. *Primer on HFCs*, pp. 4, 9, 10. Institute for Governance & Sustainable Development. https://igsd.org/documents/HFCPrimer7July2015.pdf.
- Zeiger, Bastian, Barbara Gschrey, and Winfried Schwarz. 2014. Technical Annex: Alternatives to HCFCs/HFCs in Unitary Air Conditioning Equipment at High Ambient Temperatures. Oko-Recherche, Frankfurt/Main, Germany. https://ozone.unep.org/system/files/documents/technical%20annex_unitary%20air%20conditioing.pdf.