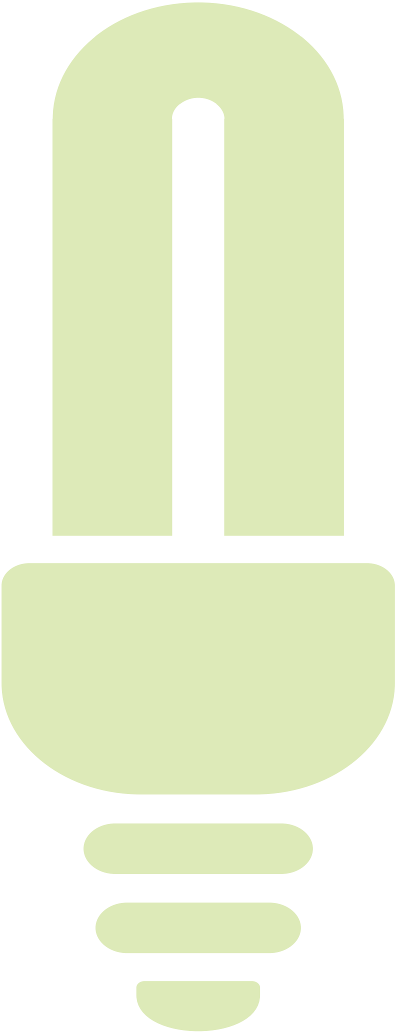
BRIEFING NOTE A

The Importance of Energy Efficiency in the Refrigeration, Air-conditioning and Heat Pump Sectors

UN environment
United Nations
Environment Programme



MAY 2018

1.

Scope of the briefing note

The Ozone Secretariat has prepared three briefing notes to support parts A, B and C of the 9–10 July 2018 Vienna workshop on energy efficiency opportunities in the context of phasing-down hydrofluorocarbons (HFCs).

This briefing note, intended for part A, provides an overview of energy and carbon related issues, looking in particular at:

- the rising demand for cooling and the growth of refrigeration, air-conditioning and heat pump (RACHP) equipment in global electricity consumption and peak demand;
- cooling-related greenhouse gas (GHG) emissions;
- energy efficiency opportunities in the RACHP sectors and HFC phase-down; and
- the multiple benefits of more efficient RACHP equipment.

This note also addresses briefly the technical potential for improving RACHP energy efficiency, as well as policy measures, financing and barriers to efficiency. Briefing Notes B and C explore these topics in more detail.

The purpose of this information note is to provide a background for the parties. It is not meant to be exhaustive or in any way prescriptive.

2.

Rising demand for cooling and growth of RACHP related electricity consumption

Increasing average global temperatures due to climate change, economic growth and urbanization are widely expected to lead to a greater demand for cooling. Any efforts to limit access to cooling would likely create major productivity losses as well as adverse impacts on the provision of quality health care, nutritious food, and education, thereby undermining the efforts and opportunities for dozens of countries to realize the UN Sustainable Development Goals, such as ending poverty, hunger and disease[1].

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[1] **Cooling for All, 2017: An inquiry into sustainable, affordable and efficient cooling pathways.**

RACHP equipment and systems are already widely used throughout the economy, from small domestic equipment (e.g. refrigerators and room air-conditioners) to very large commercial and industrial systems (e.g. large building air-conditioning and food processing refrigeration). According to current estimates, RACHP equipment represents between 25% and 30% of the global consumption of electricity[2].

Global RACHP related energy consumption is expected to surge as much as 33-fold by 2100 versus current levels to more than 10,000 TWh[3]. The lion's share of this growth will be in emerging economies / developing countries. In addition to the major trends already mentioned – climate change, economic growth and urbanization – several additional factors are driving this growth:

- **i.** air-conditioning is becoming more widely used in homes, in the workplace and in cars;
- **ii.** the cold chain[4] is being strengthened to support initiatives to reduce food wastage; and
- **iii.** heat pumps are being introduced to reduce GHG emissions from heating systems.

Assessments made by the International Energy Agency forecast that the number of air conditioners in use globally will increase from 1.5 billion to 5.5 billion units between 2015 and 2050 (figure 1)[5]. Meanwhile, the number of domestic refrigerators would double to more than 2 billion[6].

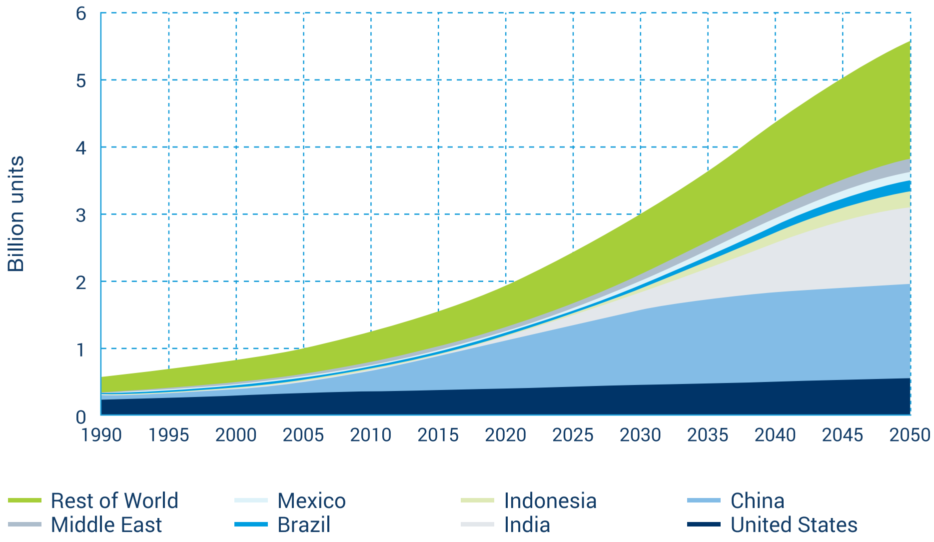

Figure 1: Project growth of global air conditioner stock between 2015 and 2050 (Source: IEA)

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[2] Ecofys, 2015: Savings and benefits of global regulations for energy efficient products. [1 TWh = 1 million MWh]

[3] Henley, J., 2015: World set to use more energy for cooling than heating.

[4] The cold chain refers to the use of refrigeration to preserve foodstuffs in the chain between agriculture and consumption i.e. after harvesting, during food production and distribution, in food retail and in domestic refrigerators.

[5] International Energy Agency, 2018, The Future of Cooling: Opportunities for energy efficient air-conditioning.

[6] International Energy Agency, 2017: Energy Technology Perspectives.

Studies from Mexico suggest a strong correlation between rising income levels and a rise in the use of air-conditioners, particularly in hot regions, with penetration levels reaching over 80%[7]. Many developing economies, meanwhile, are poised for an explosion in room air-conditioning use as millions of households cross the income threshold that makes air-conditioning affordable.[8]

3.

Impact of rising electricity consumption for cooling on peak electrical demand

Greater use of RACHP equipment is already creating significant stresses on power systems and increasing peak electricity demand, especially in high ambient temperature countries. As cooling demand grows further, countries will need to consider the need for significant investment in power generation equipment and in electricity transmission and distribution systems.

In high ambient temperature countries, peak electrical demand occurs when the demand for air-conditioning is particularly high. Figure 2 illustrates the way air-conditioning equipment dominates peak demand in Australia (the peak load is 3 times higher on hottest days compared to mild days).

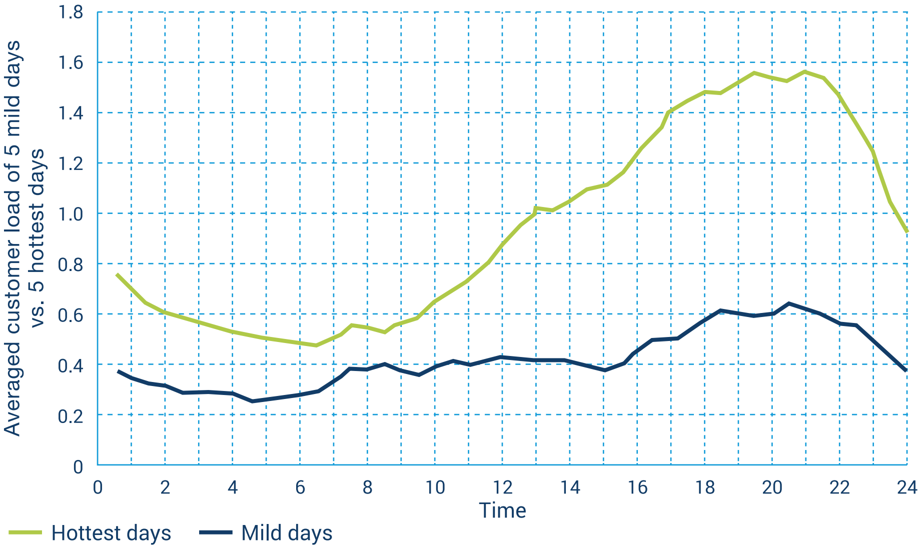

Figure 2: The impact of air-conditioning on peak electricity demand

Ausgrid, Australia (Smith et al., 2013)

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[7] **Davis, L., 2016: The global impact of air conditioning: big and getting bigger.**

[8] **McMahon, J., 2017: World's Hottest Market: air conditioners for India and hundreds of new electric plants to power them.**

These peak electricity demands will increase significantly as the predicted growth in air-conditioning takes place. Air conditioner sales are growing at 10–15% per year in hot, populous countries such as Brazil, China, India and Indonesia[9]. It is worth considering that a typical room air-conditioning unit uses 10–20 times as much electricity as a ceiling fan[10].

4.

RACHP related GHG emissions

RACHP equipment generates two distinct types of GHG emissions:

i. Direct emissions created by leakage of refrigerants, during operation, maintenance and at end-of-life; and

ii. Indirect emissions generated at the power station supplying the electricity used by the RACHP equipment (if the power is generated from fossil fuels).

The majority of GHG emissions related to RACHP equipment are indirect emissions. According to the Green Cooling Initiative[11], over 70% of GHG emissions from refrigeration systems are due to indirect emissions from electricity generation, as illustrated in figure 3.

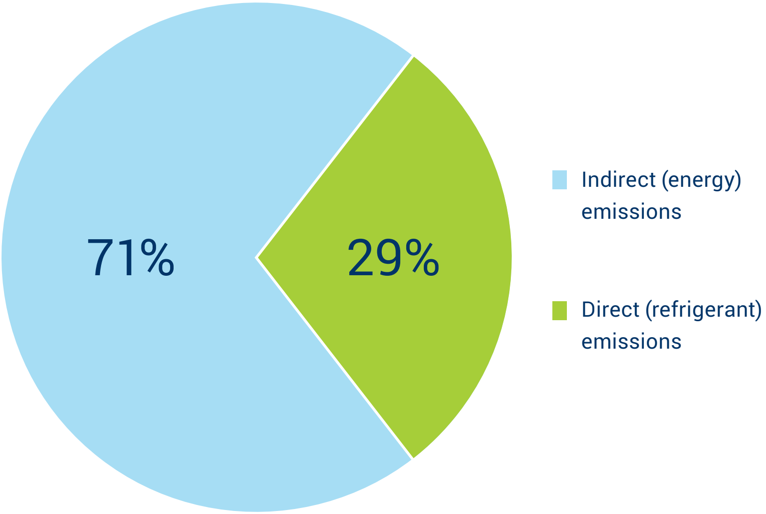

Figure 3: Global split of GHG emissions from refrigeration systems

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[9] Birmingham Energy Institute, 2017: Clean Cold and The Global Goals.
[10] Cooling for All, 2017: An inquiry into sustainable, affordable and efficient cooling pathways.
[11] GIZ, 2015: Green Cooling Technologies, Market trends in selected refrigeration and air conditioning subsectors.

The split between direct and indirect GHG emissions depends on various factors such as:

- the GWP of the refrigerant used;
- the refrigerant charge and the amount of refrigerant leakage that occurs during different stages of the equipment lifecycle (mainly operational leakage and emissions at end-of-life);
- the energy demand of the RACHP system and the hours of usage; and
- the CO_2 emissions factor of the power station(s) supplying the electricity used[12].

For small sealed equipment (such as domestic refrigerators), the indirect emissions are even more dominant – usually well over 95% of total GHG emissions. Some types of larger systems (such as large supermarket systems or industrial systems) have historically had high levels of leakage and the direct refrigerant emissions can represent up to around 40% of the total – although emissions from energy generation remains the larger part of the emissions.

In 2014, RACHP equipment was responsible for just over 7% of global greenhouse gas (GHG) emissions, equivalent to 3.7 gigatonnes (Gt) CO_2 per annum[13], including both direct emissions from HFC leakages and indirect emissions from electricity generation required to power RACHP systems. Forecasts suggest these emissions will increase to 8.1 Gt CO_2 in 2030, representing around 13% of projected global GHG emissions at that time[14]. This means that emissions from RACHP systems are growing at least three times faster than the global average increase of GHG emissions.

5.

Energy efficiency opportunities in the RACHP sectors and HFC phase-down

Most HFCs are in cooling systems, which are significant users of energy (usually electricity). In RACHP equipment using HFC refrigerants, both the electrical energy consumed and the leakage of the refrigerants used are significant sources of GHG emissions. For most RACHP applications, the CO_2 emissions from the generation of the energy used, constitutes the largest part of total GHG emissions.

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[12] The CO_2 emissions factor represents the amount of CO_2 emitted per kWh of electricity generated. This depends on the method of generation, the type of fuel used and the efficiency of the generating equipment.

[13] GIZ, 2015: Green Cooling Technologies, Market trends in selected refrigeration and air conditioning subsectors.

[14] See footnote 8.

Refrigerants with lower global warming potential (GWP) will only create reductions in total GHG emissions if their energy efficiency is equal to or higher than the energy efficiency of high GWP refrigerants. In many cases, the low-GWP refrigerants being used to replace high-GWP HFCs and HCFCs are at least as efficient, if not more.

Parties to the Montreal Protocol have recognised the importance of energy efficiency in the context of the HFC phase down[15]. At the Twenty-Eighth Meeting of the Parties to the Montreal Protocol, held in Kigali in 2016, it was noted in decision XXVIII/3 that the refrigeration and air-conditioning sectors represent a substantial and increasing percentage of global electricity demand. The parties agreed that improvements in energy efficiency could deliver a variety of co-benefits for sustainable development, including energy security, public health and climate change mitigation. The decision further highlighted the large returns on investment that have resulted from modest expenditures on energy efficiency and the substantial savings available for both consumers and governments.

Energy efficiency will continue to be an important consideration as part of the phase-down of HFCs under the Kigali Amendment. Decision XXIX/10 of the Twenty-Ninth Meeting of the Parties to the Montreal Protocol, held in Montreal in 2017, addressed issues related to energy efficiency while phasing down HFC. This decision:

- recognised the importance of maintaining and/or enhancing energy efficiency while transitioning away from high-GWP HFCs to low-GWP alternatives in the RACHP sectors;
- noted that the use of refrigeration and air conditioning is growing in Article 5 parties; and
- highlighted that enhancing energy efficiency could have significant climate benefits.

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[15] For example, decision XXVIII/2 (paras. 16 and 22), decision XXVIII/3, decision XXIX/10.

6.

Recognising the multiple benefits of improved RACHP energy efficiency

Traditionally, three main benefits accrue by improving RACHP equipment efficiency:

i. Energy cost savings for end-users;

ii. Avoidance of costs from building new electric power generators to meet peak demand; and

iii. Reduced GHG emissions.

1. End-user operating cost benefits

Many of the available energy efficiency improvements create positive financial returns for the end user. The cost of energy dominates the lifecycle cost of most RACHP equipment, as illustrated in figure 4[16]. Over the life of the equipment, the cost of energy can be around five times the original capital cost. End users can accrue significant financial return over the lifetime of their equipment by opting for more energy efficient alternatives.

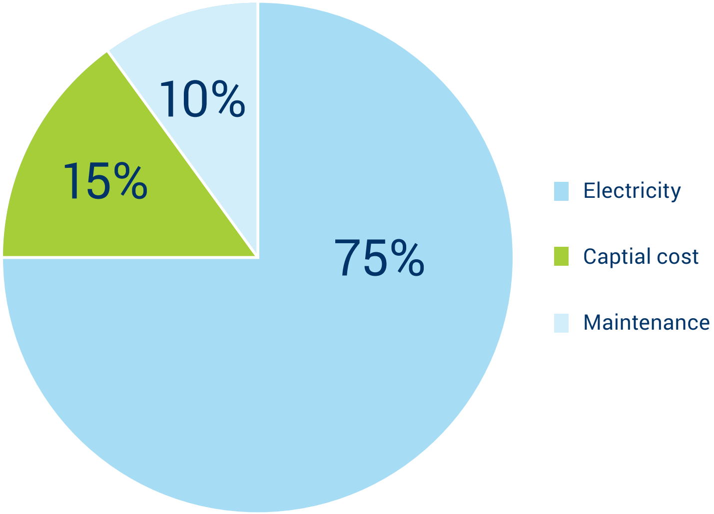

Figure 4: Example RACHP lifecycle costs

2. National electricity infrastructure cost benefits

In most countries, there will be further financial benefits related to avoided investment required to expand or upgrade electricity supply systems. Improving RACHP equipment efficiency can lead to a lower peak electricity demand and

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[16] Food and Drink Federation, 2007: Refrigeration Efficiency Initiative, Purchase of Efficient Refrigeration Plant.

hence avoided costs related to building additional power stations and electricity transmission and distribution networks.

A 2015 Lawrence Berkeley National Laboratory (LBNL) study showed that combined transition to low-GWP refrigerants and energy-efficient room air conditioners could produce savings in peak electrical demand equal to 540–1,270 gigawatts (GW) by 2050, the equivalent of 1,000 to 2,500 power plants of 500 MW size[17]. Most of these projected savings are attributed to the efficiency improvements.

3. Reduced GHG Emissions

As noted above, for most RACHP equipment, the indirect GHG emissions from energy use dominate total emissions. Improving energy efficiency therefore creates a significant opportunity to reduce those GHG emissions.

The same 2015 LBNL study also showed that the cumulative GHG emissions abatement from the global stock of room air conditioners alone could be over 25 Gt of CO_2 by 2030 if 30% more efficient technologies were used.

In addition to these three primary benefits for increasing energy efficiency, there are other benefits which accrue to different actors. For example, reduction in energy consumption will result in improved local air quality for citizens, improved national energy security, increased productivity and macroeconomic development (figure 5). These multiple benefits of energy efficiency are discussed in further detail by the International Energy Agency[18].

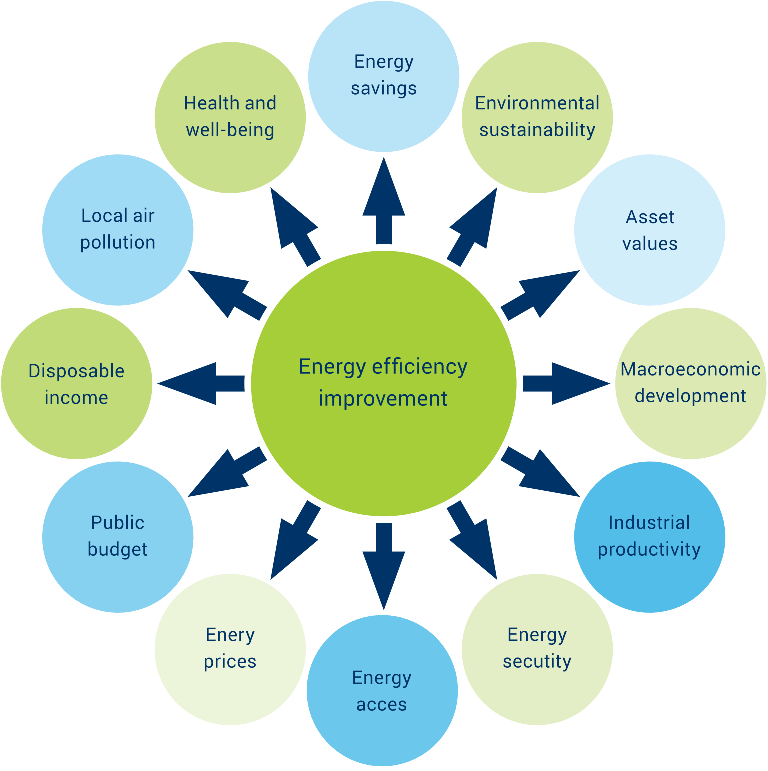

Figure 5: The multiple benefits of energy efficiency (Source: International Energy Agency, 2014: Capturing the Multiple Benefits of Energy Efficiency)

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17 Lawrence Berkeley National Laboratory (LBNL), 2015: Benefits of Leapfrogging to Super-efficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning.

18 International Energy Agency, 2014: Capturing the Multiple Benefits of Energy Efficiency.

These multiple benefits of energy efficiency also contribute towards achieving UN Sustainable Development Goals (SDGs). For example, these include:

- Affordable and clean energy (SDG7)
    - ☐ By 2030, ensure universal access to affordable, reliable and modern energy services (SDG7.1)
    - ☐ By 2030, double the global rate of improvement in energy efficiency (SDG7.3)
- Good health and well-being (SDG3)

7.

The potential for RACHP energy efficiency improvements

Numerous studies have illustrated the significant potential for the cost-effective improvement of the energy efficiency of RACHP equipment[19]. To maximise efficiency, designers and end users should apply a holistic approach that includes:

- efforts to reduce the need for cooling (cooling load);
- selection of appropriate equipment type and size, with high efficiency cycles and components;
- use of appropriate controls to maximise efficiency under all operating conditions; and
- application of good installation, operating and maintenance practices to support high efficiency operation throughout the life of the equipment.

Figure 6 provides a high-level overview of some of the different approaches to achieving greater RACHP efficiency.

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[19] Two examples: Shah et al, 2015: Energy efficiency benefits in implementing low global warming potential refrigerants in air conditioning. SKM Enviros, 2015: Use of Refrigeration in UK Soft Drinks Supply Chain.

MINIMIZING COOLING LOAD (30–60%)
Building design
Shading
Insulation
Doors on retail displays

EQUIPMENT AND CONTROL (30–70%)
High efficiency heat exchangers
High efficiency compressors
Optimized refrigeration cycle
Good controls (e.g. variable speed drives)

OPERATION AND SERVICING (15–30%)
Managing existing stock
Timely servicing
Performance measurement /
fault diagnosis

REFRIGERANT SELECTION (5–10%)
Choice of most appropriate refrigerant

Figure 6: Potential for RACHP efficiency improvements (with indicative savings ranges)[20]

Notes to figure 6: The percentage ranges are only indicative. Higher and lower figures are possible. For efficiency improvements involving multiple measures, the savings are not additive.

Efficiency improvement opportunities are greatest during the design and/or purchase of new equipment. In many situations, however, there are also good opportunities to achieve energy savings through better use of existing equipment. Briefing Note B provides more detail on options and approaches for RACHP efficiency improvements.

8.

Cost impacts of energy efficiency improvements

The various cost impacts of improving energy efficiency of RACHP equipment can be summarised as follows:

i. All energy efficiency improvements provide energy cost savings for the end user.

ii. Many efficiency improvements involve some extra capital cost, e.g. to use a variable speed motor instead of a fixed speed motor.

iii. For cost-effective efficiency improvements, any extra capital cost is recovered over a period of time out of the energy savings. Many RACHP efficiency opportunities have payback periods in the range of one to three years.

iv. Some efficiency improvements do not require any extra capital investment but may require some extra time input from management or maintenance technicians, e.g. adjusting an incorrect control setting.

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[20] Based on Presentation by TERI at Montreal Protocol OEWG side event, 2017.

v. As a new high efficiency technology matures it is likely that any capital cost difference between low and high efficiency designs will fall. This is especially important for small mass-produced equipment such as domestic refrigerators and room air-conditioners, where the markets are very competitive.

Figure 7 illustrates how the energy consumption of refrigerators in the US has reduced by 75% over 40 years, whilst the cost for buying a fridge has fallen in real terms by 50%. The diagram also shows that during this time the average size of refrigerators has grown by 25%. The introduction and tightening of minimum energy performance standards has a significant impact in driving this type of change.

vi. There are also cost benefits that relate to the impact of improved efficiency on the electricity supply infrastructure and are not visible to the end user. Better efficiency means less investment in power stations and electricity transmission and distribution.

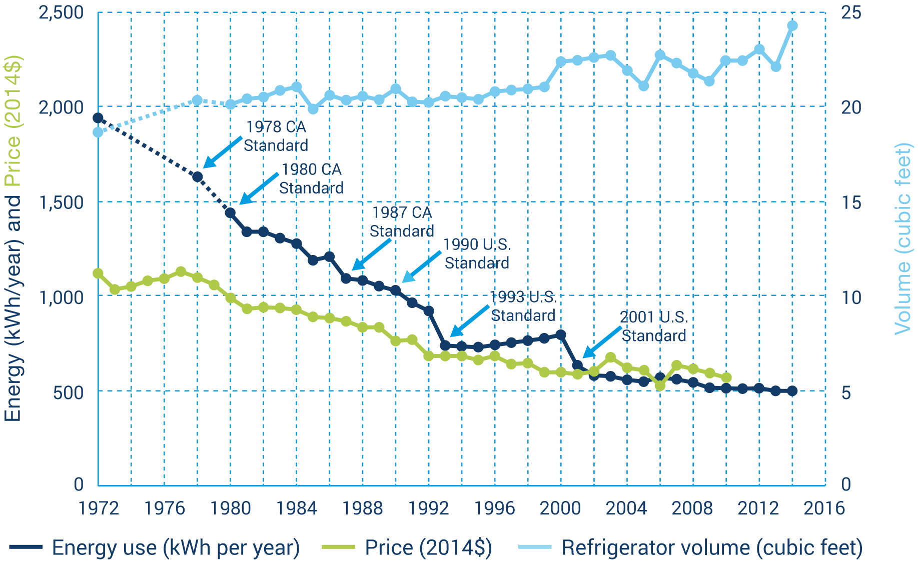

Figure 7: Average Household Refrigerator Energy Use, Volume, and Price Over Time[21]
(Sources: Association of Home Appliance Manufacturers (AHAM) for energy consumption and volume; U.S. Consus Bureau for price.

Notes: a. Data includes standard size and compact refrigerators.
b. Energy consumption and volume data reflect the current DOE test procedure.
c. Volume is adjusted volume, which is equal to fresh food volume + 1.76* freezer volume
d. Prices present the manufacturers selling price (e.g. excluding retailer markups) and reflect products manufactured in the U.S.

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[21] U.S. Association of Home Appliance Manufacturers, 2016: Appliance Standards Awareness Project.

9.

Barriers to maximising energy efficiency in RACHP equipment

Numerous studies have documented the main barriers that are slowing the uptake of high efficiency RACHP systems[22]. Many of these barriers are similar to those that apply to energy efficiency technologies such as heating, lighting and industrial processes. Briefing Note C provides further details on barriers, which generally fall into the following categories:

- **Information barriers,** whereby equipment purchasers and end users may not have access to all the information required to make informed choices about the best available technologies on the market;
- **Financial barriers and market failures,** where purchasers may not have the financial resources to buy high efficiency RACHP equipment and/or may base investment decisions on low upfront/capital cost rather than lifecycle cost;
- **Misaligned incentives and behavioural barriers,** meaning developers, such as residential property developers, may not have an incentive to invest in RACHP equipment with a higher upfront but lower lifecycle cost, or end-users may be unaware of – or unwilling to – adopt maintenance regimes that would increase the efficiency (and reduce related GHG emissions) of their equipment; and
- **Governance barriers,** including a lack or government resources, capacity and/or expertise, particularly at the local level, to enact, implement and enforce new policies and regulations.

The combined effect of these and other barriers is an imperfect market characterised by the on-going use of sub-optimal equipment. It is worth adding that barriers vary in importance between countries and regions. For example, awareness and technical barriers are likely to play a bigger role in markets where the market for high efficiency RACHP solutions is less developed, whereas market and finance barriers are likely to be the biggest challenges in markets that have more experience pursuing high efficiency RACHP opportunities.

Ultimately, addressing barriers likely requires some form of policy intervention by governments in order to incentivize and maximize the uptake of best in class, high efficiency RACHP equipment.

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[22] See for example: Cooling for All, 2017: An inquiry into sustainable, affordable and efficient cooling pathways. progRESsHEAT, 2017: Using Renewable Energy for Heating and Cooling: Barriers and Drivers at Local Level. Becque, R. et al, World Resources Institute, 2016: Accelerating Building Efficiency: Eight Actions for Urban Leaders. International Energy Agency, 2010: Energy Efficiency Governance.

10.

Policies and interventions to address the barriers to high efficiency RACHP

The basic formula for an effective policy suite to overcome barriers and create an enabling market for energy efficiency generally includes a combination of three basic ‘ingredients’:

i. **regulations;**
ii. **information;** and
iii. **incentives.**

This combination of policies is commonly used across the energy efficiency spectrum to promote a range of efficient technologies such as home appliances.

To be effective, this policy suite should also include national policies for building energy codes and standards (regulations), fiscal policies (incentives), and equipment energy labels and capacity-building programmes (information). Any national government also needs to support energy-efficiency policies at the local level, where investment decisions are taken and implemented. An effective policy suite should therefore also include local polices for land-use planning and building energy code enforcement (regulations), targeted financial incentives for buildings, equipment and pilot and demonstration projects[23]. Policy responses also need to address the capacity needs in the public system for policymaking, implementation, enforcement and sector development.

Briefing Note C provides further details on policies and interventions, and takes a closer look at complementary financing and investment mechanisms.

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[23] **IEA, 2016: World Energy Technology Perspectives.**

11.

Concluding comments

Increasing average global temperatures due to climate change, economic growth and urbanization are widely expected to lead to a greater demand for cooling. It has been projected that, during the period of time in which the use of HFCs is being phased-down under the Kigali Amendment, the use of RACHP equipment will grow rapidly and significantly, particularly in emerging economies. Without improvements in the energy efficiency of RACHP equipment, this growth in cooling equipment use will put a major strain on electricity grids and lead to a substantial increase in greenhouse gas emissions.

There is an important interplay between RACHP-related electricity consumption increases, GHG emissions and the HFC phase-down. Policy makers and other stakeholders working to phase-down HFCs have begun to consider this interplay to ensure policies and measures are complementary rather than counter-productive.

The RACHP market is not likely to maximise the uptake of high efficiency equipment without support and encouragement of governments. Policy interventions and incentives will be critical to avoid the negative effects of rising electricity consumption and GHG emissions resulting from an unprecedented increase in global cooling demand.