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EXECUTIVE COMMITTEE OF
THE MULTILATERAL FUND FOR THE
IMPLEMENTATION OF THE MONTREAL PROTOCOL
Eighty-fourth Meeting
Montreal, 16–20 December 2019

UPDATED SUMMARY OF THE REPORT BY THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL ON MATTERS RELATED TO ENERGY EFFICIENCY WITH REGARD TO THE ISSUES IDENTIFIED IN DECISION 82/83(e) (DECISION 83/64)

Background

1. At its 82nd meeting, the Executive Committee considered a document prepared by the Secretariat presenting a summary of the Parties' deliberations at the 40th Meeting of the Open-Ended Working Group (OEWG) of the Parties and the Thirtieth Meeting of the Parties to the Montreal Protocol in relation to the report by the Technology and Economic Assessment Panel (TEAP) on issues related to energy efficiency (EE).[1]

2. Subsequent to a discussion, the Executive Committee decided *inter alia*:

(e) To discuss, at its 83rd meeting, ways to operationalize paragraph 22 of decision XXVIII/2, and paragraphs 5 and 6 of decision XXX/5, including:

(i) Initiatives associated with maintaining and/or enhancing the EE of replacement technologies with low- or zero-global-warming potential (GWP) in the refrigeration, air-conditioning and heat-pump (RACHP) sector, such as:

a. Methodologies to quantify changes in EE; and

b. Technical interventions associated with maintaining and/or enhancing EE;

(ii) Cost-related issues such as associated incremental costs, payback opportunities and costs of monitoring and verification;

(iii) Possible environmental benefits, particularly those associated with climate; and

(f) To request the Secretariat to prepare, for consideration by the Executive Committee at its

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[1] UNEP/OzL.Pro/ExCom/82/65 and Add.1

83rd meeting, a summary of the report by the TEAP on matters related to EE[2] with regard to the issues identified in sub-paragraph (e) above (decision 82/83).

An analysis of decision 82/83(e) and (f)

3. Decision 82/83(e) and (f) includes specific paragraphs of two decisions of the Meetings of the Parties:

(a) Paragraph 22 of decision XXVIII/2: To request the Executive Committee to develop cost guidance associated with maintaining and/or enhancing the EE of low- or zero-GWP replacement technologies and equipment, when phasing down HFCs, while taking note of the role of other institutions addressing energy efficiency, when appropriate;

(b) Paragraph 5 of decision XXX/5: To request the Executive Committee to build on its ongoing work of reviewing servicing projects to identify best practices, lessons learned and additional opportunities for maintaining EE in the servicing sector, and related costs; and

(c) Paragraph 6 of decision XXX/5: To request the Executive Committee to take into account the information provided by demonstration and stand-alone projects in order to develop cost guidance related to maintaining or enhancing the EE of replacement technologies and equipment when phasing-down HFCs.

4. Incorporating the text of the above-mentioned decisions, substantive coverage of the decision 82/83(e) and (f) would read as follows:

> To request the Secretariat to prepare for the 83rd meeting, a summary of the TEAP Decision XXIX/10 task force report on issues related to EE while phasing down HFCs (TEAP task force report), so that the Executive Committee could discuss:
>
> (a) The development of cost guidance associated with maintaining and/or enhancing EE of RACHP equipment when converting from HFCs to low- or zero-GWP technologies, which should:
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> (i) Include initiatives such as methodologies to quantify changes in EE and technical interventions associated with maintaining and/or enhancing EE;
>
> (ii) Include associated incremental costs, payback opportunities and costs of monitoring and verification;
>
> (iii) Include possible environmental benefits, particularly those associated with climate;
>
> (iv) Take into account the information provided by the demonstration projects for the introduction of low-GWP technologies in Article 5 countries and the HFC stand-alone investment projects approved by the Executive Committee; and
>
> (v) Take into account the role of other institutions addressing EE, when appropriate; and
>
> (b) Maintaining or enhancing EE when phasing-down HFCs in the refrigeration servicing sector taking into account best practices, lessons learned and additional opportunities for

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[2] TEAP May 2018: Decision XXIX/10 task force report on issues related to energy efficiency while phasing down hydrofluorocarbons (Volume 5).

maintaining EE identified from ongoing refrigeration servicing sector plans.

5. In line with decision 82/83(e) and (f), at its 83rd meeting, the Executive Committee considered document UNEP/OzL.Pro/ExCom/83/42, presenting a summary of the report of the TEAP on matters related to EE, and agreed to discuss the document in the contact group formed to discuss matters relating to EE. Subsequently, in reporting back to the Committee the convener of the contact group indicated that owing to time constraints, the contact group was unable to discuss the document. In light of this, the Committee decided to defer its consideration to the 84th meeting (decision 83/64).

Scope of the document

6. The document presented to the 83rd meeting, was based on the TEAP task force report prepared prior to May 2019. Subsequently, in May 2019 and September 2019, the TEAP task force issued revised reports[3]. In reviewing the updated report issued in September 2019, the Secretariat noted that it contained a detailed assessment on technology, availability and cost aspects of EE associated with air-conditioning (AC) and self-contained commercial refrigeration equipment (SCCRE); the report also removed some sections that were included in the Secretariat's document presented to the 83rd meeting. Given the substantive additional information contained in the TEAP task force report that would be useful for the discussion of the matter by the Executive Committee, the Secretariat considered relevant to revise the document presented to the 83rd meeting (most of the additional information is contained in Annexes II to VI to the present document. To facility the review of the present document, new text is highlighted[4] while the text that has been removed is shown as "strike through" text.

7. The present document, which is an update of the document presented to the 83rd meeting, consists of the following sections:

Section I	Summary that highlights the main aspects covered by the TEAP task force report in relation to paragraphs (e) and (f) of decision 82/83
Section II	Introduction to EE in the context of HFC phase-down and adoption of low- and zero-GWP technologies
Section III	Technical interventions associated with maintaining and/or enhancing EE
Section IV	Costs related issues, including associated incremental costs, payback opportunities and costs of monitoring and verification
Section V	Environmental benefits in terms of CO_2-equivalent
Section VI	Demonstration projects for the introduction of low-GWP technologies and HFC stand-alone investment projects

8. The present document also consists of the following six annexes:

Annex I	Glossary of terms extracted from the TEAP Task Force Report with a few additional explanations (this Annex is presented as an easy reference on terminology used in the document)
Annex II	Availability of air-conditioners operating with different refrigerants and at

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[3] TEAP September 2018: Decision XXIX/10 task force report on issues related to energy efficiency while phasing down hydrofluorocarbons (Volume 5) - Updated final report.

[4] The text in the new Annexes II to VI is not highlighted to facilitate its reading.

	different EE levels[5]
Annex III	Information on availability, cost and energy efficiency impact and application to climate region for different components related to EE for medium- and low-GWP refrigerants for air-conditioners and SCCRE[6]
Annex IV	Availability of components for AC equipment with low- and medium-GWP refrigerants
Annex V	Availability of components for air-conditioners and SCCRE low- and medium-GWP refrigerants
Annex VI	Additional costs relating to production line and component changes for producing domestic air-conditioners using flammable refrigerants and cost and performance analysis of energy efficient refrigeration and AC equipment [7]

9. In line with decision 82/83(f), the information contained in the present document has been extracted from the TEAP task force report with some editorial changes.[8] A few editorial changes have been introduced, and clarifications and additional information have been provided based on inputs from an independent technical expert who reviewed this document. The sequence of the information contained in the present document does not follow that of the TEAP task force report. No information from other sources has been included as this was not requested under the decision.

10. The Executive Committee may wish to note that the following two documents fully addressed the requirements of paragraph 5 of decision XXX/5, and therefore matters related to the refrigeration servicing sector are not addressed in the present document:

(a) Preliminary document on all aspects related to the refrigeration servicing sector that support the HFC phase-down (decision 80/76(c)) (UNEP/OzL.Pro/ExCom/82/64); and

(b) Paper on ways to operationalize paragraph 16 of decision XXVIII/2 and paragraph 2 of decision XXX/5 of the Parties (decision 82/83(c)) (UNEP/OzL.Pro/ExCom/83/40).

11. The Executive Committee may also wish to note that at its 84th meeting, it will consider an updated paper on information on relevant funds and financial institutions mobilizing resources for energy efficiency that may be utilized when phasing down HFCs (decision 83/63)[9]. The paper considers the role of other institutions addressing EE; therefore, this matter is not included in the present document.

I. SUMMARY THAT HIGHLIGHTS THE MAIN ASPECTS COVERED BY THE TEAP TASK FORCE REPORT

12. Historically, the implementation of the Montreal Protocol has focused on the phase-out of ODS

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[5] It includes information on the availability of HCFC-based, high-GWP HFC based and medium- and low-GWP refrigerant based products in different markets.

[6] It includes information on compressors, heat exchangers, controls and other components/product performance improvement measures for energy efficient operations with medium- and low-GWP technologies.

[7] It provides information on capital cost ranges and operating performance and cost analysis for energy efficient equipment production in AC and refrigeration equipment.

[8] The TEAP task force report includes Annex A with information on sector specific challenges to the uptake of technologies. Most of the relevant information relating to Annex A is covered under Section III of the present document; additional information on adoption of technologies are also presented in Annexes II to V.

[9] UNEP/OzL.Pro/ExCom/84/68

and alongside resulted in EE improvement of equipment and products[10]. During the transition to alternative refrigerants, the industry has made efforts to improve the design improvement of equipment and components affordable to the consumers and this effort over a period of time, has resulted in energy efficient products at lower inflation adjusted price of products. AC systems are receiving increasing attention due to needs for refrigerant technology change and efforts are underway to optimise the systems and components for achieving energy-efficient cooling with new refrigerants. Factors including energy pricing and billing schemes and energy labelling play an important role in energy efficient technology adoption.

13. The largest potential for EE improvement comes from improvements in total system design and components, which can yield efficiency improvements (compared to a baseline design) that can range from 10 per cent to 70 per cent (for a “best in class” unit). Integrated approach to RACHP equipment design and selection that includes ensuring minimisation of cooling/heating loads, selection of appropriate refrigerant, use of high efficiency components and system design, ensuring optimised control and operation, under all common operating conditions and designing features that will support servicing and maintenance, can contribute to energy savings; this would result in reduced greenhouse gas (GHG) emissions over the life of equipment, reduced energy costs to the end-user and reduced peak electricity demand that would result in lower investments in power generation and distribution capacity.

14. Refrigerant selection is a trade-off between environmental benefits, safety, thermodynamic cycle efficiency, system design and reliability, and cost. The impact of refrigerant choice on the EE of the units is usually relatively small – typically ranging from +/- 5 to 10 per cent. AC and commercial refrigeration (CR) equipment meeting the minimum EE requirements are widely available for all refrigerant families including HCFCs[11]; no development to achieve higher EE is taking place on HCFC equipment due to the phase-out schedule of this refrigerant. Where markets and supporting policies provide clear signals towards alternative refrigerant choice, manufacturers invest in research and development (R&D) for those refrigerants while maintaining or enhancing EE. As a consequence, the R&D effort on EE is focusing on refrigerants with lower GWPs. Some components to enhance EE in AC and commercial refrigeration equipment with lower GWP refrigerants are not widely available, while components for medium-GWP refrigerants are more widely available with some countries transforming the majority of their consumption to these refrigerants.

15. Most of the widely available new technologies contributing to higher EE equipment are not directly impacted by intellectual property (IP) considerations. However, for technologies from a limited number of suppliers, emerging technologies, or R&D technologies, IP considerations has to be determined on a case-by-case basis.

16. In relation to technical interventions for maintaining/enhancing energy efficiency, high ambient temperature (HAT) environment imposes an additional set of challenges on the selection of refrigerants, system design, and potential EE enhancement opportunities. At HAT, system designs which maintain energy efficiency are affected by the refrigerant choice due to thermodynamic properties, safety requirements due to the increased charge, and component availability and cost. Research at HAT conditions done so far has shown the viability of some low-GWP alternatives to deliver comparable EE results to existing technologies. Further research, as well as private sector efforts, continue to focus on the optimisation of design to achieve targeted efficiencies for those alternatives. The technical, financial, market, information, institutional/regulatory, service competency and other challenges along with the mitigation measures that can be undertaken are given in the report. The PRAHA-II project funded under

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[10] The implementation of the Montreal Protocol has resulted in gradual improvement of EE; this has also happened before the Protocol was adopted. Further, implementation of the Montreal Protocol has in many cases accelerated EE improvement, as the change of refrigerant often also was an incentive to move to a higher technology level as a result of better product redesign.

[11] This may not be the case in case of some technologies (e.g., R-290-based air-conditioner).

the Multilateral Fund is re-testing optimized units using efficient compressors and heat exchangers, which were rebuilt from the original prototypes used in PRAHA-I.

17. HAT conditions are not generally an issue for SCCRE which are often placed inside air-conditioned stores and shops. However, in Article 5 parties, SCCRE are sometimes placed outdoors to prevent additional heat load inside the building and this will impact performance due to HAT.

18. There are methods developed by various countries with established market transformation programs for promoting EE including minimum energy performance standard (MEPS) programmes and labelling programmes. A “snapshot” of the cost of efficiency improvement programme at any given time will tend to provide a conservative (i.e. higher) estimate of the cost of efficiency improvement. In actual practice, the prices of higher efficiency equipment have been found to decline over time in various markets as higher efficiency equipment begins to be produced at scale. This applies especially for small mass-produced equipment where manufacturers quickly absorb the initial development costs and try to get to certain “price points” that help them sell their equipment.

19. Retail price of products is not an adequate indicator for the costs of maintaining or enhancing EE in new equipment due to bundling of various non-energy related features with higher efficiency equipment, variation of manufacturer’s skills and know-how, variation in manufacturer’s pricing, marketing and branding strategies, and the idea that efficiency can be marketed as a “premium” feature. Information on analysis of costs and payback period shows that a variety of factors influence the payback for equipment that could have higher initial costs and there is a ceiling of energy efficiency beyond which the payback from energy savings over lifetime of equipment is not attractive. Rigorous cost analysis may be needed to fully understand the impact of EE improvements. These types of analyses are relevant when setting MEPS as several EE levels need to be evaluated compared with the baseline. These studies can take more than one year to conclude for a single product category.

20. Information on capital and operating costs associated with transitioning to low-GWP options in standalone commercial refrigeration equipment, condensing units, centralised and distributed system and air-conditioning and heat-pump equipment as well as matrix of technical interventions to achieve higher EE and associated cost estimates shows that a range of factors affect overall costs of transition to alternative low-GWP refrigerants and improvement in energy efficiency. Operating practices play a significant role in energy efficient performance of equipment.

21. Refrigerant cost accounts for about 1 per cent of the overall RAC equipment cost. It is predicted that HFC costs will rise as phase-down progresses, making low-GWP refrigerants increasingly cost-competitive. Compressors account for about 20 per cent of the cost of RAC equipment. Efficiency can be improved by up to 20 per cent by technical advances, but cost increases proportionately. Heat exchangers of the “fin and tube” type have improved their efficiency with the introduction of small diameter tubes; most recently, the switch to micro-channel heat exchangers, which have similar or marginally lower cost (about 5 per cent), up to 5 per cent higher efficiency, and reduced refrigerant charge by about 40 per cent, has been accelerating. Optimising airflow improves EE. The power and cost of fans increase in a stepwise fashion, leading to a complex relationship between increasing cost and EE. The costs of other technologies, including self-cleaning to reduce dust deposition, are marginal. As the cost for efficient components and designs decrease over time due to increases in scale of production or learning, the cost of higher efficiency equipment decreases. As this occurs, higher levels of efficiency pay back over shorter periods.

22. There are also a wide variety of co-benefits of improved EE in addition to lower energy costs to the consumer, avoided CO_2 emissions, and avoided peak load such as avoided mortality and morbidity caused by energy poverty, comfort benefits, avoided SOx, NOx and particulate matter emissions, and avoided CO_2 emissions in addition to direct economic benefits. For different operating environments and weather conditions, the CO_2 emission impacts can be different.

23. The adoption of common standards for testing and qualification methods between markets would enable manufacturers to capitalize on scale and accelerate technology readiness. Governments setting testing and performance requirements that are not comparable with their main trading partners or suppliers may disadvantage that country economically by delaying the adoption of new energy efficient technologies in that country.

24. Detailed information on costs associated with monitoring and reporting of EE improvement is not available in the report, no information is presented in this document.

25. Finally, the document provides information available as of date, on demonstration projects for the introduction of low-GWP technologies while phasing-out HCFCs. Further, as the results of stand-alone investment projects for HFC phase-out approved in light of decision 78/3(g) are not available, a listing of these projects is provided.

II. INTRODUCTION TO EE IN THE CONTEXT OF HFC PHASE-DOWN AND ADOPTION OF LOW- AND ZERO-GWP TECHNOLOGIES

26. Historically, the implementation of the Montreal Protocol has focused on the phase-out of ODS and alongside resulted in energy efficiency (EE) of equipment and products[12]. The Multilateral Fund has provided financial and technical assistance to support Article 5 Parties in the achievement of their ODS phase-out targets.

27. While phasing out CFCs in the domestic refrigeration sector, CFC-12 was phased out to either hydrocarbon R-600a or HFC-134a. Initially HC blends had been used but this resulted in increased energy costs. R-600a, with better EE, then became the favoured option other than HFC-134a. HFC-134a with similar EE, but higher GWP, was limited to regions where concerns about flammability and related liability were significant market barriers.

28. The industry made great efforts to improve EE when transitioning from CFC-12, mainly through better compressor and system designs. The global best practice refrigerator in 2015 has GHG emissions that are nine times lower than a typical 1980s refrigerator sold in non-Article 5 countries. The domestic refrigerator market is highly cost-competitive and benefits from enormous economies of scale via mass production. The cost of the high efficiency 2015 refrigerator is lower in real terms than the 1980s model (Figure 1[13]).

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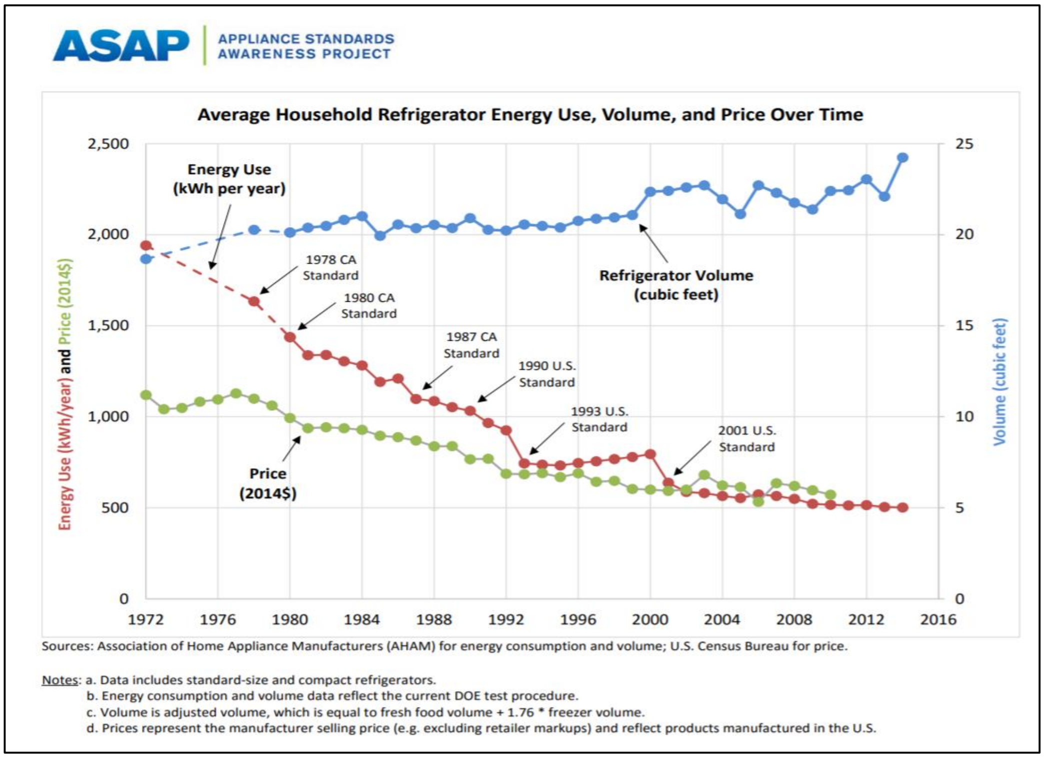
[12] The context has been explained in footnote to paragraph 10 of the document.

[13] https://appliance-standards.org/sites/default/files/refrigerator_graph_Nov_2016.pdf



Sources: Association of Home Appliance Manufacturers (AHAM) for energy consumption and volume; U.S. Census 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 represent the manufacturer selling price (e.g. excluding retailer markups) and reflect products manufactured in the U.S.

Figure 1. Average household refrigerator energy use, volume and price in the United States of America

29. The United States unitary AC equipment evolution since the 1970s has shown steady efficiency improvement while at the same time achieving cost effectiveness as shown in Figure 2. United States manufacturers have reduced the inflation-adjusted price of unitary AC equipment for residential central ducted AC systems (equipment costs only).[14] The trend of decreasing prices has been concurrent with the ODS phase-out, as well as periodically increased efficiency standards. The reasons for this trend are complex, including technological innovations and manufacturing efficiencies, as well as macroeconomic factors related to globalization of manufacturing and commodity price trends. The adjusted equipment price didn't increase following the introduction of the efficiency standards or the increase in the standards. Prices didn't react adversely with the ban of HCFC-22 in 2010.

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[14] The dotted green line depicts the Producer Price Index (PPI) while the blue line depicts the inflation adjusted PPI. The inflation adjustment is calculated by dividing the PPI series by the gross domestic product chained price index for the same years and normalize them to the year 2015.

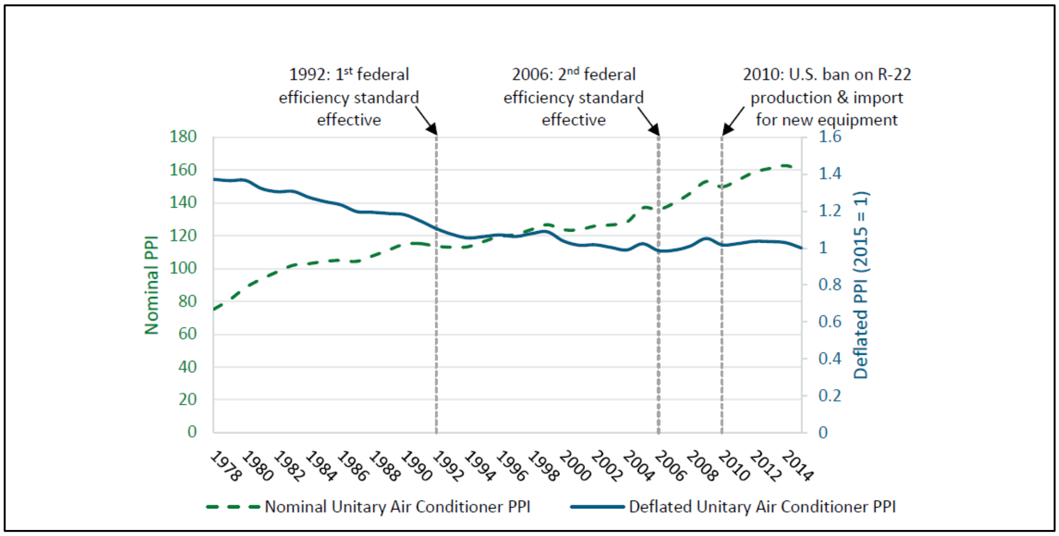

Figure 2. Residential central AC equipment costs from 1978 to 2015 [Goetzler et al 2016]

30. The phase-out of HCFC-22 is still in progress in Article 5 Parties.[15] HFC-32 has been introduced in many countries. While R-290 has been introduced in a few countries, and offers an advantage in terms of EE, however, one major barrier for the use of R-290 in room air-conditioners is the flammability rating which restricts its use.

31. Annex II to the document presents the availability of the various technologies together with the MEPS ranges from various countries/regions. For information presented in the tables contained in Annex II, three tiers of MEPS as defined below are considered; and for each refrigerant category, the availability is presented as widely available (in bold font), available technology (normal font), emerging technology (italics font) and not available (in normal font with underline):

(a) Low-tier: AC units which meet a regional or country required energy efficiency MEPS;

(b) Mid-tier: AC units which are up to 10% more efficient than the base MEPS; and

(c) High-tier: AC units which are at least 10% or higher than the base MEPS.

32. In countries with MEPS, HCFCs are mainly available in the lowest efficiency tier enough to meet the MEPS criteria, with few exceptions. High-GWP HFCs, mainly R-410A, are available everywhere in the low-tier.

33. Currently a wide range of room air-conditioners are being sold, with EEs that vary from very low to very high. The level of EE bears little relationship to capacity, or to purchase price [Shah et al., 2017, Kuijpers et al., 2018]. The optimization of performance of room air-conditioners requires attention to compressor, refrigerant charge and size of the heat exchanger. Studies with R-290, HFC-32 and HFC-161, compared to a HCFC-22 system, demonstrated that the energy efficiency ratio (EER) of the optimized room air-conditioners was within 10 per cent, irrespective of the refrigerant, whereas without full system optimization, the variations in EER exceeded 10 per cent.

34. In certain countries, air-conditioners consume up to 70 per cent of the generated electric power due to the excessive use of cooling almost all year round and for long hours. The public is aware of the burden that AC adds to their financial situation and hence could be more willing to welcome regulatory and other measures to lessen that burden through the use of more efficient systems which consume less power. This

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[15] HCFC-22 phase-out is largely in AC applications both manufacturing and servicing.

is not the case where utilities are subsidized, so that the cost of energy to the consumer is low, which removes any incentives for improving the EE of systems including those to be installed.

35. Another challenge is the billing scheme that utilities use for their residential, commercial, and industrial clients. Some countries use one billing rate across the hours of the day but increase the rate according to the consumption bracket. While this scheme can work reasonably well for residential customers, it penalizes large commercial/industrial customers operating larger, more efficient plants like district cooling if these plants are not taken in consideration.

36. Energy labelling of units and energy programmes are a step in the right direction. Most countries have energy labelling schemes for domestic air-conditioners and refrigeration units. One of the challenges of energy labelling and meeting energy standards in general is the testing and verification process to ensure that the stated levels are true and have been verified. More information relating to energy labelling and energy standards policies are discussed in Section 4 of the TEAP task force report; as this does not directly fall within the scope of this decision, EE policy and labelling related information is not included in the present document.

III. TECHNICAL INTERVENTIONS ASSOCIATED WITH MAINTAINING AND/OR ENHANCING EE

37. To provide cooling or heating, RACHP equipment and systems consume energy, which is, in most cases, electricity. The amount of energy consumed by a unit, is related to the quantity of cooling/heating load that needs to be provided (the amount of cooling or heating service) and to the energy needed to deliver that service. A more energy efficient unit or system will deliver the same amount of service for a lower level of energy consumed.[16]

38. Improvements to the EE of equipment are best addressed when new equipment is designed and manufactured. The designer can incorporate appropriate energy saving features that will deliver multiple benefits including:

(a) Reduced energy-related GHG emissions throughout the life of the equipment;

(b) Reduced energy costs, providing good financial benefits to the end user; and

(c) Reduced peak electricity demand, providing potential financial benefits by reducing the need for electricity generation and distribution capacity, which translates into lower investment, fuel and costs of operation for electricity generators.

39. By using a rigorous integrated approach to RACHP equipment design and selection, the opportunities to improve EE can be maximized. This approach includes:

(a) Ensuring minimisation of cooling/heating loads;[17]

(b) Selection of appropriate refrigerant;

(c) Use of high efficiency components and system design;

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[16] The International Energy Agency (IEA) defines EE as “a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input.

[17] This could be directly related to more energy efficient equipment design and selection, but it should be taken into account in an integrated approach because of its importance in reducing energy consumption overall.

(d) Ensuring optimised control and operation, under all common operating conditions; and

(e) Designing features that will support servicing and maintenance.

40. Each of these five requirements is discussed in the following paragraphs.

Ensuring minimisation of cooling/heating loads

41. Eliminating or reducing loads can significantly reduce energy consumption while still delivering the desired level of heating or cooling capacity. Some examples of load reducing actions include:

(a) Building design features that reduce summer heat gains (e.g.; shading, reflective roof materials, location of windows, insulation);

(b) Putting doors on retail refrigerated display cabinets;

(c) Pre-cooling of hot products prior to refrigeration (e.g., in a food factory using cooling tower water to pre-cool a cooked product);

(d) Reducing heat created by electrical auxiliaries such as evaporator fans, chilled water pumps or lighting; and

(e) Reducing cold storage heat load with improved insulation and prevention of warm air entering through open doors.[18]

42. Reducing loads may require extra investment, e.g., added insulation, orientation of building shading or adding a door to a display cabinet case. However, the reduced cooling load may result in some capital cost savings due to, e.g., smaller-sized refrigeration systems and reduced electric interconnection rating.[19]

Selection of appropriate refrigerant

43. Refrigerant selection is a trade-off between environmental benefits, safety, thermodynamic cycle efficiency, system design and reliability, and cost. The impact of refrigerant choice on the EE of the units is usually relatively small, ranging from +/- 5 to 10 per cent. Designers should select the best refrigerant from an efficiency perspective but should also address the wide range of other design issues. It is also important to note that technologies resulting in energy efficiency improvement opportunities available for high-GWP refrigerants may be applicable to low-GWP refrigerants as well.[20]

44. Simplified thermodynamic analysis demonstrates the relative impact of different refrigerants on the EE of the unit, which can help designers create a “short-list” of options. For a given application, there will be a limited number of refrigerants that are likely to be within ±5 per cent of the baseline refrigerant(s) in terms of energy performance. A thermodynamic analysis provides a useful starting point but it is essential to consider “real-world” performance, which is based on the way the refrigerant interacts with the various system components, in particular the compressor and heat exchangers. This can be illustrated with the comparison of HCFC-22 and R-410A for use in small room air-conditioners. A thermodynamic analysis shows efficiency advantages for HCFC-22, but the most efficient equipment currently available on the market uses R-410A. This reflects the fact that equipment manufacturers stopped research and development to improve HCFC-22 equipment after the HCFC phase-out began under the Montreal Protocol. Modern R-410A equipment has a number of efficiency innovations not available with HCFC-22, making the

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[18] Reduced sizing. For example, a domestic refrigerator should not be chosen larger than needed or a cold store should not be chosen larger than required.

[19] The cost reduction due to reduced cooling load is often experienced.

[20] Technologies resulting in EE improvements are generally also applicable to low-GWP refrigerants.

efficiency of R-410A higher. A thermodynamic analysis of HFC-32 shows it has an advantage of about 5 per cent over R-410A for small building air-conditioners.

45. In comparison with HCFC-22, a thermodynamic cycle analysis of propane (R-290) shows coefficient of performance (COP) loss ranging from -2 per cent to zero per cent dependent on the evaporating temperature. However, the volumetric capacity for R-290 is consistently lower than HCFC-22 by approximately 14 per cent. Drop-in testing of R-290 in HCFC-22 equipment showed that COP improvement of 7 per cent and capacity reduction of 8 per cent compared with HCFC-22 at standard rating conditions. This is primarily attributed to the improved transport properties of R-290 versus HCFC-22. With engineering optimisation, HCFC-22 alternatives such as R-290, can match or exceed the performance of existing HCFC-22 units with efficiency increase of up to 10 per cent.

46. AHRI AREP[21] resulted in 67 reports on alternative refrigerant evaluation and one study on benchmarking the risks associated with the use of A2L refrigerants. The performance of the alternative refrigerants ranged widely depending on the type of the study (drop-in or soft optimized), the equipment, and the baseline refrigerant. Overall, the HCFC-22 alternatives were shown to have similar capacity performance results within ±10 per cent but efficiency ranging from -20 per cent to -5 per cent compared to the baseline HCFC-22. The R-410A alternatives showed capacity and efficiency ranging from ±15 per cent and the R-404A alternatives showed capacity ranging from -20 per cent to -5 per cent and efficiency improvement up to 10 per cent.

47. The Unites States Department of Energy (US DOE) studies focused on split air-conditioners and package air-conditioners and extended the evaluation to 55°C ambient conditions. The study showed that the HCFC-22 fluorinated alternatives resulted in 3 per cent to 14 per cent capacity loss and 11 per cent to 16 per cent efficiency loss at 35°C rating condition and 3 per cent to 14 per cent capacity loss and 7 per cent to 15 per cent efficiency loss at 55°C. However, R-290 resulted in 7 per cent capacity loss and 11 per cent efficiency improvement at 35°C rating condition and 10 per cent capacity loss and 8 per cent efficiency improvement at 55°C. R-410A alternatives showed capacity difference ranging from -14 per cent to 5 per cent at 35°C rating condition and from -3 per cent to 13 per cent at 55°C, and efficiency difference ranging within ±5 per cent at 35°C and up to 6 per cent at 55°C.

48. The research studies so far concentrated on performance of low-GWP alternative refrigerants compared to the presently used ODS and high-GWP HFC technologies. The studies used available products with “soft optimisation” of charge and expansion devices. Further, research is needed to study the impact of full optimisation into new products using low-GWP alternatives with changes to the compressors, heat exchangers, and other components.

49. In the case of AC equipment, refrigerants with flammability classes A2L and A3 had some challenges and require countries to include them in their local regulations.[22] HFC-32 and R-290 can be obtained from several suppliers all over the world. The demand for R-290 has been more or less stable and is covered by the present production. The same is true of HFC-32 although there has been an increase in demand lately. The demand for both refrigerants, however, remains small compared to R-410A.

50. The refrigerants used in commercial refrigeration were limited to HCFC-22, R-404A and HFC-134a. This is changing with the introduction of CO_2, hydrocarbon-based units (R-600a or R-290), and HFO blends (based on HFO-1234yf) in many countries.[23]

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[21] Alternative Refrigerants Evaluation Program.

[22] Class A2L are low flammable refrigerants (e.g. HFC-32); Class A3 are refrigerants with high flammability, such as hydrocarbons (e.g., HC-290, HC-600a); Class A2 refrigerants are those with flammability between A2L and A3, but their availability is not yet significant.

[23] HFC-based refrigerants are also reported to be used in very small quantities in commercial refrigeration.

Use of high efficiency components and system design, and ensuring optimised control and operation

51. Vapour compression RACHP equipment consists of a number of primary components (e.g., evaporator, condenser, compressor, expansion valve, refrigerant) and secondary components (e.g., fans, pumps and cooling towers). To maximize EE, it is important to: select an appropriate "system design" that defines the overall system arrangement and operating temperature levels; and select individual components that can contribute to the system efficiency. Controls can be treated as another component of a RACHP system, but it is helpful for the designer to consider the control and operation of the system as a separate issue. In terms of costs, as a general rule, it can be said that effective control technologies offer a cost-effective EE strategy.

52. Equipment is designed to achieve a nominal design point, which is the peak cooling load during the hottest expected ambient conditions.[24] This design point can be considered as the "worst case" load condition. In reality, most systems spend very few hours per year close to this design point. Most of the time, the cooling load is lower when the weather is cooler. In a well-controlled system, the EE should improve at conditions away from the design point. For example, in cool weather, the condensing temperature should fall, giving a potentially significant increase in efficiency; in a poorly controlled system, these improvements do not occur, and the efficiency might degrade more as compressors operate at part-load capacity.

53. The following are examples that can illustrate EE improvements related to systems design, components, and optimized controls:

(a) Cooling at appropriate temperature level: To maximize efficiency, RACHP systems should provide cooling at the maximum possible temperature level. Raising the evaporating temperature by just 1°C can improve efficiency by between 2 per cent and 4 per cent. A common design is to group several cooling loads onto one cooling system, even though the temperature requirement is different for each load. The evaporating temperature has to suit the coldest load – which means that the warmer loads are being cooled inefficiently. A system design that separates loads at different temperatures can be significantly more efficient, but this comes at the additional cost for multiple systems. Another example is the choice of chilled water temperature within a space cooling system – using a higher temperature provides better efficiency for the same cooling load;[25]

(b) Compressor: System designers consider the optimum number of compressors to suit a given load. For very small systems, there is always one compressor. However, for larger systems it may be more efficient to select several small compressors rather than one large one, with a trade-off being made between the extra capital cost and the resulting energy savings. This is especially important to support high efficiency under part-load operating conditions. The compressor needs to be optimised for the refrigerant selected and the expected range of operating conditions (in terms of evaporating and condensing temperatures). There can be as much as a 20 per cent difference in efficiency between two compressors of similar size and cost. Good selection can provide good efficiency improvement at little or no extra cost. When a cooling load falls e.g., due to change in ambient conditions, the compressor needs to operate at part-load as the load is lower than the system's nominal design point. On small systems this is done with on-off control and on large systems with compressor load adjusters such as cylinder unloading for reciprocating compressors or slide valves for screw compressors. These are very inefficient ways of providing part-load control. Recent advances in variable speed drives (e.g., the inverter) allow for the use of variable speed compressors, which can often deliver over a

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[24] Equipment are also designed around nominal design point that includes point of operation with maximum efficiency.

[25] This may require a larger and costlier heat exchanger.

25 per cent efficiency improvement.

(c) Heat exchanger selection: The designer should select heat exchangers with the lowest practical temperature difference to optimise evaporating temperature (which should be as high as possible) and condensing temperature (which should be as low as possible).[26] Heat exchangers with a tube-and-fin design with smaller diameter tubes have been introduced. This is aimed at improving the heat transfer rate and the EE, although the designer must also consider the impact of higher pressure drops. This can reduce the internal volume of the heat exchanger, making it possible to reduce the required amount of refrigerant. Micro-channel heat exchangers have also been developed and provide another design option.

(d) Condenser pressure control: Many RACHP systems have “head pressure control” which stops the condenser pressure floating downwards in cold weather. The use of such controls can be eliminated or minimised through improved design. For example, by using an electronic expansion valve in place of a thermostatic expansion valve the head pressure control setting can be significantly reduced. Energy savings of approximately 20 per cent are possible.

(e) Control of auxiliary pumps and fans: Many systems use fans to circulate air being cooled or pumps to circulate chilled water. Traditionally, these were fixed speed devices that are designed to suit the nominal design load. Auxiliary loads on the cold side of a refrigeration and AC system are “paid-for-twice” because as well as running the pump or fan, they create an extra heat load that must be removed by the refrigeration system. At part-load, these auxiliary loads can become a disproportionately large part of the total power consumption. By using VSDs, the fans and pumps can be slowed down at part-load.

(f) Other modification of equipment, lighting and redesign for energy efficient operations: Other interventions that would result in heat load reduction and efficient operations of equipment include use of anti-fogging glass, lower heat load bulbs such as LED bulbs, improved air-flow in equipment, other heat load minimisation interventions (e.g., cabinet doors, night blinds and covers) and leak controls.

54. TEAP report provides information on market evolution on compressors and other components for AC equipment and SCCRE and availability, cost and EE impact and application to climate region for different components related to EE for medium- and low-GWP refrigerants for these equipment. This information is given in Annexes III, IV and V, respectively.

~~Table 1 summarizes efficiency improvements for a range of component design improvements from a “base case” represented by a European MEPS.~~

~~Table 1. Efficiency improvement options and corresponding energy savings based on European conditions~~

~~Option~~	**~~Description~~**	**~~Improvement from base case (%)*~~**	
		~~Min~~	**~~Max~~**
~~Standby load~~	~~Reduced standby loads~~[27]	~~2~~	~~2~~
~~Efficient compressors~~	~~Two-stage rotary compressors, high efficiency scroll compressors with DC** motors~~	~~6~~	~~19~~

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[26] Heat exchanger selection is almost always a techno-economic selection process. The larger the heat exchanger chosen, the higher efficiency impact.

~~[27] The electricity use is just used to keep the necessary control elements active, waiting to deliver the system service and its level is generally not influenced by any refrigeration load.~~

~~Inverter/variable speed~~	~~AC***, AC/DC or DC inverter driven compressors~~	~~20~~	~~>25~~
~~Efficient heat exchanger~~	~~High efficiency microchannel heat exchangers, larger sized heat exchangers~~	~~9~~	~~29~~
~~Expansion valve~~	~~Thermostatic and electronic expansion valves~~	~~5~~	~~9~~
~~Crankcase heating~~	~~Reduced crankcase heating power and duration~~	~~9~~	~~11~~

~~(*) The cumulative efficiency improvement of multiple measures will not be the sum of all the individual components.~~
~~(**) DC: direct current~~
~~(***) AC: alternate current~~

Designing features that will support service and maintenance

55. When new equipment is being considered, the designer should consider the servicing and maintenance aspect and provide features that will help ensure good ongoing EE throughout the life of the system. Proper servicing and maintenance begins with proper installation and commissioning of equipment. Poor installation and start-up practices can reduce the EE of the equipment substantially and such losses cannot be recovered for the rest of the life of the equipment. Good monitoring and control systems can help the plant operator or maintenance technician check performance and correct any energy wasting faults. It is always better to include meters and sensors as part of a new system than to add them at a later date.

High ambient temperature (HAT) considerations

56. A HAT environment imposes an additional set of challenges on the selection of refrigerants, system design, and potential EE enhancement opportunities. System design consideration to maintain energy efficiency at HAT conditions are affected by the refrigerant choice due to thermodynamic properties, safety requirements due to the increased charge, and component availability and cost. Research at HAT conditions done so far has shown the viability of some low-GWP alternatives to deliver comparable EE results to existing technologies. Further publicly financed research, as well as private sector initiatives, are optimising design to achieve the maximum efficiency in these challenging conditions.

57. One of the most effective means to improve EE under HAT conditions is to increase the condenser size. However, this results in increased refrigerant charge and system cost. There is a need to examine the transition impact on flammability, toxicity, and operating pressures. Standards and codes development bodies are working on improved adoption of the new generation of alternative lower GWP refrigerants.

58. Variable speed devices (VSDs) also enhance EE under HAT conditions compared to “on/off” compressors. VSDs give the greatest benefit when there is a large swing in temperature over 24 hours. However, even when the temperature swing is small there are still substantial savings in “shoulder” seasons (spring and autumn). A feature of VSDs is their closer adherence to the daily cooling load/demand curve of the building, which creates savings compared to the stepped approach of “on-off” compressors.

59. The discussion about suitability of refrigerants for HAT condition has led to several large-scale testing projects where prototypes using low- and medium-GWP refrigerants were built and tested at ambient temperatures exceeding 35°C. The outcome of these tests was the identification of several refrigerants, which provide comparable efficiencies in HAT conditions. PRAHA, a project funded under the Multilateral Fund, in its second phase (PRAHA-II) is re-testing optimised units using efficient compressors and heat exchangers, which were rebuilt from the original prototypes.

60. HAT conditions are not generally an issue for SCCRE, which are often placed inside air-conditioned stores and shops. However, in developing countries, SCCRE are sometimes placed outdoors to prevent additional heat load inside the building and this will impact performance. Industry leaders have experienced that in HAT conditions the indoor ambient temperature is approximatively 5°C higher than the indoor ambient temperature in non-HAT conditions (Topten unpublished data). This increased temperature is however not sufficient to have an impact on the product’s EE.

61. Table 1 below summarizes the various considerations on the effect that HAT has on EE.

Table 1. Various considerations on the effect that HAT has on energy efficiency

Consideration	Description	Effect of HAT	Special measures
Refrigerant selection	Thermodynamic properties and flammability characteristics	Closeness to critical temperature reduces efficiency Limitation of large amount of refrigerant charge	Choice of refrigerant
System design	Cooling loads, condensing temperatures and pressures	Larger cooling loads lead to larger equipment Higher condensing temperatures and pressures	Testing the system (burst pressure, tightness, functional) to account for higher operating pressure, while maintaining efficiency
Manufacturing	Design and construction need to account for higher pressure	Need for a special design and special components to meet EE standards at HAT conditions	Local manufacturers to continuously improve design and manufacturing capabilities
Service	Service practices at higher temperatures and pressures	Risk of system failure and loss in efficiency	Technician training
Safety	Codes	Quantities of refrigerants per occupied space due to the higher heat loads Limitation due to increased charge	Risk assessment

Challenges for the uptake of energy efficient technologies

62. More energy efficient equipment and systems in RACHP sectors are already available. For example, a study on efficiency of different air-conditioner models found that best available air-conditioner models were two to three times more efficient than average models on the global market. This indicates there is major potential for significant energy savings using equipment that is already on the market in the RACHP sector. More ambitious standards, labels, and other types of market-transformation policies (e.g., incentives, procurement or awards) would reduce the energy requirements of countries where energy is already at a premium.

63. High-efficiency products typically, but not always, have a higher up-front cost compared with low-efficiency products. This is partly because high-efficiency models are often sold as premium products bundled with other non-energy features.[28] Higher-efficiency products also tend to have a wider range of market prices compared with lower-efficiency products. The introduction of overly stringent efficiency standards could inadvertently raise prices, if not done carefully, often with step changes agreed with air-conditioner manufacturers. In order to minimise the adverse impacts of market measures such as MEPS, these measures should be designed with a long-term goal in mind and at a schedule in line with the pace of technology development and investment cycles in the relevant sector.

64. The barriers to adoption of EE measures are within the following categories: technical, financial, market, information, institutional and regulatory, service competence, and other. These barriers and mitigation measures are described in Table 2.

Table 2. Challenges for the uptake of energy efficient technologies and means for removing them

Barrier	Description	Mitigation measure	Implementation (years)
Technical	Testing facilities to evaluate, measure and verify EE may not be available at	Installation of appropriate testing facilities	1-3

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[28] An important aspect of costs of high-efficiency products relates to high cost of components.

Barrier	Description	Mitigation measure	Implementation (years)
	all, or lack sufficient resources or capacity to meet the demand. Local manufacturers may lack the technical capacity to manufacture high efficiency equipment. Intellectual property may be a barrier to manufacturing high efficiency components	Training and capacity building for local manufacturers Technology transfer of intellectual property, or design of joint venture programmes/collaborative research and development	
Financial	Higher efficiency equipment generally costs more to produce than less efficient equipment. Efficient components are frequently bundled with other features and sold at a premium.[29] The availability cost of finance plays a significant role	Low-cost financing, utility rebate programmes, bulk procurement programmes, buyer's clubs and other types of procurement programmes	1-2
Market	Purchasers of equipment may be different than the users of the equipment, e.g. in rental housing. This can be a barrier to the purchase of the higher efficiency equipment as the incentive to do so is not available to the purchaser	Incentives to purchasers of efficient equipment	0.5-1
Information	Information regarding the availability or benefits of higher efficiency equipment may not be available to the end-user. EE metrics can be too technical or hard to understand. This type of barrier can be partially addressed through mandatory or voluntary labelling schemes, star ratings, or other types of education and awareness programmes	Mandatory or voluntary EE labelling programmes, awareness and education campaigns	0.5-1
Institutional/ regulatory	There may be a lack of legislation for EE, a non-existent or weak regulatory framework, weak or unenforceable standards or a lack of technical capacity to enforce EE related activities such as standards or labelling	Enactment of appropriate legislation and regulatory frameworks, design of appropriate evaluation measurement and verification mechanisms, capacity building for regulators and policymakers, harmonization of MEPS	2-4
Service competency	High efficiency equipment may require use of the latest technology that requires new technician skills. If there is skill gap between that required for the equipment selected and the competency of the service provider, high efficiency equipment might not be used	Training programmes for service technicians	1-3
Other	There may be misperceptions about high efficiency products, that they may suffer in terms of quality and/or	Awareness and education programmes on benefits of energy efficient equipment including payback periods	0.5-1

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[29] Research has shown that over time, and with increasing scale of production the prices of more efficient equipment has come down in most markets. However, at any particular time, the most efficient equipment will still tend to be sold at a premium, even if the market as a whole tends toward higher efficiency.

Barrier	Description	Mitigation measure	Implementation (years)
	maintenance or other performance criteria[30]		

IV. COST RELATED ISSUES ASSOCIATED INCREMENTAL COSTS, PAYBACK OPPORTUNITIES AND COSTS OF MONITORING AND VERIFICATION

65. The economic benefits of improving EE are well documented, and vary by equipment type, application, weather, time and by local factors such as discount rates, hours of use, electricity prices, transmission and distribution losses.[31]

66. The most frequently cited benefits of EE improvement are energy, cost and GHG saving and, for space cooling, peak load reduction. Transition to low-GWP refrigerants would further add to these savings.[32]

67. In addition, there is avoided morbidity and mortality caused by energy poverty, reduced days of illness, improved comfort, reduced pollution (SOx, NOx and particulate matter), and avoided CO_2 emissions. It has been estimated that these co-benefits can provide an additional 75 per cent to 350 per cent to the direct energy-savings benefits of EE.[33]

Methodology to calculate capital and operating costs

68. Various parties have established market transformation programmes for promoting EE including MEPS and labelling programmes. For example, the US DOE’s Appliance and Equipment Standards Program and the preparatory studies for the EU Ecodesign Directive both use “bottom-up” engineering analysis based on data collection, testing and modelling of the more efficient equipment to identify the actual manufacturing cost (as opposed to the retail price) of efficiency improvement. This “bottom-up” approach usually uses industry standard equipment design software[34] and test data of higher efficiency equipment to identify design options for higher efficiency equipment from a “base case” model representing low or average efficiency on the market in question. Subsequently, the costs of these higher efficiency design options are surveyed by interviewing industry experts, manufacturers and component suppliers to build up a picture of the costs of higher efficiency equipment.

69. This methodology offers a “snapshot” of the cost of efficiency improvement at any given time and will tend to provide a conservative (i.e., higher) estimate of the cost of efficiency improvement. In actual practice, the prices of higher efficiency equipment have been found to decline over time in various markets as higher efficiency equipment begins to be produced at scale. This applies especially for small mass-produced equipment where manufacturers quickly absorb the initial development costs and try to get to certain “price points” that help them sell their equipment.

70. Similar processes have also been used to a more limited degree to support EE standards processes in countries such as China and India. While this methodology can be used generally to estimate the costs to the manufacturers of maintaining and/or enhancing EE for both Article 5 and non-Article 5 Parties with

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[30] “Unproven reliability” as these products are new to the market; installers, customers, etc. may be reluctant to apply the new technology.

[31] The US Energy Information Administration estimated that the average construction cost for new generators in 2016 is roughly US $2,000/kW of capacity, i.e., over US $2 billion per new power plant if financing costs are included. https://www.eia.gov/electricity/generatorcosts/

[32] This can be done simultaneous to introduction of high EE products.

[33] Ürge-Vorsatz et al., 2014.

[34] For example, [Fridley et al 2001] used the Oak Ridge National Laboratory (ORNL) Heat Pump Design Model, Mark V, version 95d [ORNL, 1996; Fischer & Rice, 1983; Fischer et al. 1988].

manufacturing capacity, the costs to the consumer of maintaining and/or enhancing EE are likely to be similar for all Parties with the additional costs of shipping for importing Parties.

Data collection

71. Due to the proprietary nature of business operations, there is limited publicly available data on capital and operating costs to the manufacturer attributable to improvements in EE for RACHP equipment. Furthermore, a glance at retail prices and efficiencies of equipment on the global market shows a wide variation in the prices of equipment at similar efficiency levels, indicating that retail prices alone are not a good indicator of the cost of maintaining and/or enhancing EE in new equipment.

72. Several examples of data collected in order to develop the methodology are presented below.[35]

(a) Retail prices are not sufficient to understand the cost of maintaining and/or enhancing EE: Figure 3 provides an example of small unitary variable speed air-conditioners with a cooling capacity of 3.5kW and EE level of about 4.5 Watt to Watt (W/W) (measured according to the Annual Performance Factor (APF) metric) in China.[36] Retail prices varies from approximately US $500 to US $2,000, i.e., a four-fold (400 per cent) variation. This effect of wide price variation at a single efficiency level holds for multiple cooling capacities, multiple efficiency levels and across both fixed-speed and variable speed air-conditioners;

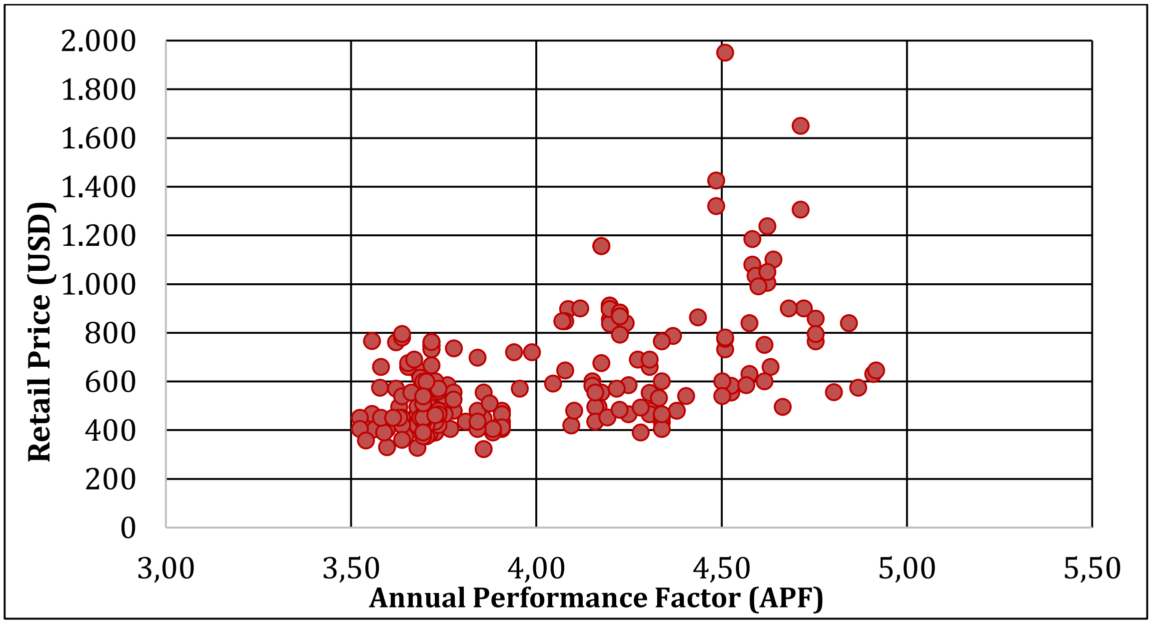

Figure 3. Retail price versus efficiency of 3.5kW mini-split air-conditioners on the Chinese market. Source: Shah, Park and Gerke, 2017

(b) A review of the air-conditioner market in Japan shows that air-conditioners on the market have a higher range of EE. Whilst there is a strong underlying association between the EE and the unit price, there remains a wide variation in price at a particular efficiency level. Figure 4 depicts the correlation between price and EE for all 3.5 kW models operating with HFC-32 as the refrigerant. The rate of price increase is roughly US $603 per EE (APF)

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[35] Methodology for cost assessment was presented by the TEAP task force report based on data collected as presented in the document.

[36] Lawrence Berkeley National Laboratory’s IDEA database and the Chinese National Institute of Standardization database.

point.

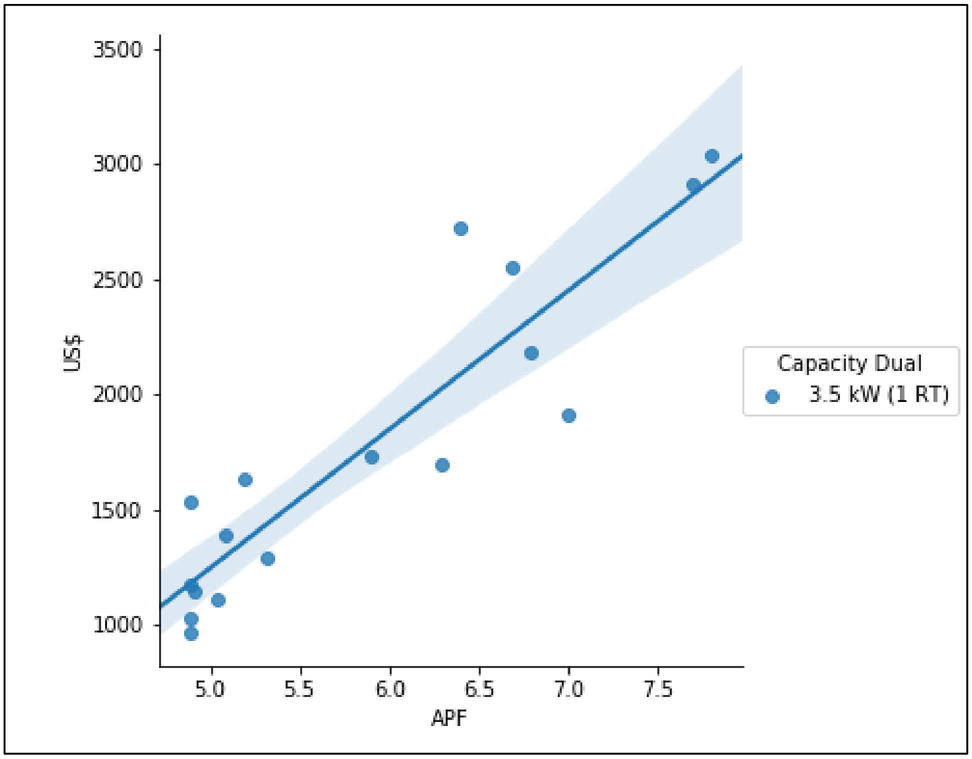

Figure 4. Survey of retail price vs EE in APF of mini-split air-conditioner in the Japanese market

(c) Costs and energy savings of various efficiency improvement options: Table 3 shows efficiency improvement options for various components for a 5.27 kW mini-split air-conditioner with expected energy savings from the "base case" model and their corresponding costs per unit in India.

Table 3. Efficiency improvement options, energy savings and manufacturing cost for a 5.27 kW mini-split air-conditioner in India

Technology	**Energy saving (%)**	**Incremental manufacturing cost (US $[37])**
Improved compressors	5.5 – 15.0	1.43 – 12.27
Variable speed compressors	21.0 – 23.0	25.67 -115.54
Variable speed drives for fans and compressors	26.0	44.93 – 134.79
Heat exchanger improvement	7.5 – 24.0	10.48 – 156.90
Expansion valve	3.5 – 6.5	1.78 - 32.09

(d) Price increase of efficiency with and without change in refrigerant: For one Chinese brand, the price increase for an approximately 13-15 per cent efficiency improvement for a 3.5 kW variable-speed air-conditioner using R-410A was about 6 per cent. However, when both the efficiency and refrigerant were updated (i.e. from 5-8 per cent improvement and from R-410A to HFC-32), the price increase was about 11 per cent.

73. The TEAP task force has estimated the additional capital cost required for the manufacturing equipment using a flammable refrigerant, in comparison to the two baseline refrigerants R-410A and HCFC-22 for mini-split AC units up to 10 kW (cooling/heating) capacity and the baseline HCFC-22 for

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[37] 1 US $ = INR 70.11

SCCRE. The information on estimates of additional cost to convert from R-410A or HCFC-22 manufacturing lines to flammable refrigerants made by the TEAP task force is given in Table 4 below.

Table 4: Task Force estimates of maximum additional cost to convert from R-410A or HCFC-22 (high GWP, non-flammable) manufacturing lines to flammable refrigerants

Item/Description[38]	Sub-Item	Max additional cost per cent over the baseline refrigerants
Production/ assembly line changes	Heat exchanger equipment for smaller tubing for better EE[39]*	100%
	Refrigerant charging units	30%
	Testing area changes (electrical panels, piping accessories)	30%
	Charging area changes including refrigerant tanks and accessories	100%
	Refrigerant distribution within the plant	100%
	Labour cost	15%
Safety requirements for charging and testing area	Ventilation system	30%
	Control system	30%
	Leak detection system	30%
	Anti-static floor	Variable
	Labour cost for O&M for safety system	Variable
IP/technology know-how cost	IP / know-how cost	Variable
	Design-software development*	Variable
	Testing facility modifications and changes	50%
	Training the employees for safety requirements	10%
	External consultants and experts*	Variable
Logistics and handling	Storage area for flammable refrigerants modification changes cost	200%
	Shipping cost in land and sea freight	Variable
	Refrigerant distribution within the plant	Variable
	Extra cost for insurance for factory and employees	Variable
	Certification cost for regulatory bodies	20%
	Training for employees	30%
	Training for jurisdiction party(s)	30%
	Awareness in/out the company	30%

(*) Provides opportunity for EE (highlighted cells).

74. The TEAP task force also provides details of modifications and/or replacements required in production process for producing domestic AC equipment using flammable refrigerants. The details of the costs are presented in Annex VI to the present document.

Cost and payback period to the consumer for different efficiency levels

75. Table 5 shows the lifecycle cost (retail price plus installation cost plus energy cost over the lifetime of the equipment) and payback period (period of time over which the energy savings exceed the higher installation cost) to the consumer calculated using the above outlined methodology from a US DOE rulemaking document[40] for four efficiency levels above a base level considered for mini-split air-conditioner. The higher efficiency levels have higher installed costs, but lower lifetime operating costs. The data imply that at the current technology development that there is a ceiling of efficiency at which point the energy savings will not pay back the higher installed cost within the lifetime of the equipment.

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[38] Some sub-items are not required in the manufacturing lines for R-410A refrigerant.

[39] The heat exchanger with smaller tube diameter can be used in both R-410A and HFC-32 refrigerants.

[40] https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0098

Table 5. Installed cost, lifecycle cost and simple payback period to the consumer for various efficiency levels for mini-split air-conditioners in the United States of America

SEER (W/W)	Average costs 2015 (US $)			Simple payback (years)	Average lifetime (years)
	Installed cost	Lifetime operating cost	Lifecycle cost		
4.1 (base)	3,714	4,758	8,472	N/A	15.3
4.3	+38	-93	-55	4.5	15.3
4.4	+105	-189	-84	4.8	15.3
4.7	+259	-295	-36	8.2	15.3
5.6	+1,105	-602	+503	16.6	15.3

76. Table 6 shows the breakdown of the lifecycle costs of typical 5 kW air-conditioner units at three EE levels in India (2 Star, 3 Star, and 5 Star), representing roughly 90 per cent of the total market. The refrigerant contribution to the lifecycle cost is minimal (less than 1 per cent). The lifecycle cost for the 2, 3, and 5 Star units are US $1,672, US $1,704, and US $1,540, respectively. This indicates that while the system price increases from 2 Star to 5 Star, it results in a net lifecycle cost saving of US $131.22.

Table 6. Breakdown of the lifecycle cost in percentage for 5 kW R-410A air-conditioner in India at different efficiency levels[41]

Star	System price	Refrigerant price	Installation cost	Lifetime energy cost
2 Star	25.9	0.5	1.3	72.3
3 Star	30.9	0.5	1.3	67.4
5 Star	42.8	0.7	1.4	55.1

77. For the self-contained, vertical, closed, transparent display cabinets equipment class[42]. Table 7 shows the lifecycle cost savings[43] at various efficiency levels calculated using the above outlined methodology from a recent DOE rulemaking document for seven efficiency levels above the base efficiency level along with their corresponding estimated annual energy use values. The higher efficiency levels have higher installed costs, but lower lifetime operating costs. The data imply that at the technology development level during the standard setting timeframe (~2013-2014) there is a ceiling of efficiency around efficiency levels 2, 3 and 4[44] at which point the energy savings will yield the maximum benefit to consumers.

Table 7: Lifecycle cost savings at various efficiency levels calculated using the DOE methodology. Each efficiency level corresponds to a possible design option at the time of the rulemaking

Level	Annual energy use, kWh/yr	Mean values of			Life-Cycle Cost Savings				Median payback period, years
		Installed cost, 2012$	Annual operating cost, 2012$	LCC, 2012$	Average LCC savings, 2012$	Customers that experience (%)			
						Net Cost	No impact	Net benefit	
1	10,022	6,498	1,270	19,135	2,503	0.0	10.1	89.9	0.5
2	6,727	6,799	970	16,433	5,200	0.0	10.1	89.9	0.8
3	6,654	6,822	964	16,397	4,709	0.0	0.0	100	0.8
4	6,318	6,974	921	16,110	4,996	0.0	0.0	100	1.0
5	6,262	7,003	917	16,105	5,001	0.0	0.0	100	1.1
6	6,174	7,073	913	16,127	4,979	0.1	0.0	99.9	1.2
7	5,857	8,909	948	18,294	2,812	10.8	0.0	89.2	4.7

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[41] Figure 2.15 on the TEAP Decision XXIX/10 task force report converted into a table.

[42] This is one of 49 different equipment classes used by DOE to regulate commercial refrigeration equipment.

[43] This methodology is explained in section 3.5.1 of the TEAP Task Force report (September 2019).

[44] DOE considers various efficiency levels during each rulemaking which correspond to technologies, design options and combinations of design options to improve energy efficiency that are technologically feasible at the time of setting the standard.

~~Capital and operating costs~~

~~Stand-alone commercial refrigeration equipment~~

~~Transitioning from high-GWP HCFC and HFC to low-GWP options will require some investment in manufacturing and equipment. This is especially true when the transition is to flammable refrigerants such as A2L or A3 refrigerants. In general, data from the field indicates that the cost to the consumer for an R-290 stand-alone system can vary from 0 to 5 per cent over conventional systems. The higher price, if any, can often be recovered, with the lower power consumed by these newer systems.~~

~~The cost to implement the other efficiency improvement ideas will vary from small, as in the case of LED lighting, to high for the variable speed or higher efficiency compressors. Payback will depend on the cost of electricity in the respective region but since most regions regulate these systems, the market would be expected to adopt the lowest cost method to achieve the minimum efficiency required.~~

~~Transitioning to low-GWP refrigerant options will result in operating cost improvements from zero per cent up to 10 per cent depending on the refrigerant chosen. R-290 refrigerant could reduce electricity cost by 5 – 10 per cent compared to HCFC-22. Additional improvements with variable speed fans, compressors, LEDs and other efforts will further reduce the power consumption depending on the improvement that has been made.~~

~~Condensing units~~

~~Transitioning from high-GWP HCFC and HFC to low-GWP options will require some investment in manufacturing and equipment.~~[45] ~~This is especially true when the transition is to flammable refrigerants such as A2L refrigerant blends or A3 refrigerants. Thermal load reduction through better insulation, especially in walk-in coolers and freezers, use of LED lights, and some other efficiency improvement are lower first capital cost and yield gains throughout the life of the equipment. Again, payback is a function of the local cost of electricity and can vary from region to region. Regulations play a key role in which efficiency improvement gets adopted.~~

~~Transitioning from high-GWP HCFC and HFC to low-GWP options can be expected to reduce or keep flat the operating energy costs depending on the refrigerant choice made. Thermal load reduction through better insulation, especially in walk-in coolers and freezers and the use of LED lights are some examples of EE methods that yield reduced power consumption, leading to lower operating costs.~~

~~Centralized and distributed systems~~

~~Market driven economics have justified many centralized and distributed systems to adopt efficiency methods. In the case of R-744 systems, for both cascade sub-critical and especially for transcritical systems, capital costs have prevented widespread adoption, particularly in warm climates. A recent study for a small store in Europe with ten refrigerated cases,~~[46] ~~compared a distributed R-290 system to a transcritical~~ ~~CO_2~~ ~~system. The efficiency of the R-290 system was about 5 per cent better on an annual basis and about 25 per cent less capital cost than the transcritical~~ ~~CO_2~~ ~~system. In order to improve the performance of the~~ ~~CO_2~~ ~~system, ejectors or parallel compressors could be added but the initial (purchase) cost will increase.~~

~~In the case of R-744 systems, for both cascade sub-critical and especially for transcritical systems, operating costs are flat to slightly higher in the case of transcritical, compared to R-404A. While the R-290~~

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[45] ~~This is not expected to be high in case of condensing units as these equipment are generally not factory charged. Possibly some changes are made to the design, and some components for safety etc. may be needed.~~

[46] ~~http://www.emersonclimate.com/europe/en-eu/About_Us/News/Documents/FFR196-Emerson-Fact-sheet-Integral-Display-Case-Technology-EN-1711.pdf~~

~~architecture could work for a small store format, it will be difficult to justify this in a store where the refrigeration systems are much larger.~~

~~Air-conditioning and heat-pump sector~~

~~There are technologies that are shown to be cost neutral, such as advanced heat exchanger designs, rotary compressors, and variable capacity centrifugal compressors. There are others that result in a cost premium that can be reduced with time due to the economies of scale, such as the micro-channel heat exchangers and the electronic expansion valves, or remain as a premium cost element such as the variable capacity compressors for room and packaged air-conditioners.~~

~~Previous studies indicated that lower GWP HFC/HFO blends can be readily used to replace R-410A while maintaining or improving the system performance of the RACHP. However, HCFC-22 alternative lower GWP refrigerants and refrigerant blends were not able to readily match the performance. A later study by Shen et al. 2017,[47] showed that with engineering optimization, HCFC-22 alternatives can match or exceed the performance of existing HCFC-22 units with efficiency increase of up to 10 per cent.~~

~~Table 7 shows an example from a US DOE rulemaking document for capital costs of higher efficiency for four efficiency levels considered for mini-split air-conditioning by the Unites States industry as a whole.~~

~~Table 7. Industry-wide capital conversion costs for various efficiency levels (2015)~~[48]

~~SEER (W/W)~~	**~~Capital conversion costs (US $ million)~~**	**~~Shipments~~[49] ~~(million units/year)~~**
~~4.2~~	~~61.0~~	~~6.5~~
~~4.4~~	~~205.6~~	~~6.5~~
~~4.7~~	~~337.9~~	~~6.5~~
~~5.6~~	~~373.0~~	~~6.5~~

~~Matrix of technical interventions to energy efficiency and associated costs~~

~~Table 8 below presents a summary of matrix of technical interventions to improve EE and associated costs.~~

~~Table 8. Summary of matrix of technical interventions to achieve improved EE and associated costs~~

~~Equipment type~~	**~~Baseline components~~**	**~~Technical interventions~~**	**~~Energy efficiency improvement~~**	**~~Associated costs~~**
~~All~~	~~Evaporating temperature~~	~~Optimize evaporating temperature~~	~~Each 1°C increase result in 2 – 4 per cent~~	~~Low~~
~~All~~	~~Controls~~	~~Improved controls~~	~~10 – 50 per cent~~	~~Low - medium~~
~~Room air-conditioners~~	~~Heat exchangers~~	~~Increase heat exchanger size, or use advanced designs (small diameter tubes or microchannel heat exchangers)~~	~~9 – 29 per cent.~~	~~Low - medium~~
	~~Compressors~~	~~Two-stage rotary compressors, high efficiency scroll compressors with DC motors~~	~~5 – 19 per cent~~	~~Medium~~

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[47] ~~Shen B, Abdelaziz O, Shrestha S, Elatar A. 2017 "Model-based optimization of packaged rooftop air-conditioners using low-GWP refrigerants," International Journal of Refrigeration, ISSN 0140-7007, available at https://doi.org/10.1016/j.ijrefrig.2017.10.028. Accessed 12 May 2018~~

[48] ~~Trial standard levels 1,2,3 and 4 correspond to seasonal energy efficiency ratio (SEERs) of 14.5, 15.0, 16.0 and 19.0 BTU/hr/W respectively for 2 tonne mini-split air-conditioners. These "Trial standard levels" were defined differently for various product categories. (Source: DOE 2016).~~

[49] ~~Total 2015 shipments included all types of central air-conditioners and heat pump systems shipped in the United States of America.~~

~~Equipment type~~	~~Baseline components~~	~~Technical interventions~~	~~Energy efficiency improvement~~	~~Associated costs~~
		~~AC, AC/DC or DC inverter driven compressors~~	~~20 – 30 per cent~~	~~Medium~~
	~~Expansion valve~~	~~Thermostatic or electronic expansion valve~~	~~5 – 9 per cent~~	~~Low~~
	~~Standby load~~	~~Reduced standby loads~~	~~2 per cent~~	~~Low~~
~~Packaged and large air-conditioners~~	~~Compressors~~	~~Use multiple compressors to optimize part load performance~~	~~Up to 20 per cent~~	~~Medium~~
	~~Compressors~~	~~Use AC, AC/DC or DC inverter driven compressors~~	~~20 – 30 per cent~~	~~Medium – high~~
	~~Heat exchangers~~	~~Increase heat exchanger size, or use advanced designs (small diameter tubes or microchannel heat exchangers)~~	~~9 – 29 per cent~~	~~Low~~
	~~Crankcase heating~~	~~Optimize crankcase heating~~	~~9 – 11 per cent~~	~~0~~
	-	~~Fault detection and diagnosis~~	~~Up to 30 per cent~~	~~Low~~
~~Commercial refrigeration~~	~~Condenser pressure control~~	~~Minimize head pressure control (replacing thermostatic expansion valves with electronic expansion valves)~~	~~Up to 20 per cent~~	~~Low~~
	~~Compressors~~	~~Variable speed control or efficient variable capacity controls~~	~~Up to 25 per cent~~	~~Medium~~
	~~Auxiliary fans and pumps~~	~~Variable speed controls for auxiliary fans and pumps~~	~~Up to 10 per cent.~~	~~Low~~
	~~Other controls~~	~~Defrost-on-demand and adjusted suction pressure controls.~~	~~Up to 10 per cent~~	~~Low~~
	~~Crankcase heating~~	~~Optimize crankcase heating~~	~~9 – 11 per cent~~	~~0~~

V. ENVIRONMENTAL BENEFITS IN TERMS OF CO_2-EQUIVALENT

78. While the Kigali Amendment focuses on energy efficient refrigerants,[50] the industry continues in parallel with its efforts to improve EE through system re-design and reducing the load through improved building design. These actions will reduce the refrigerant charge in AC systems, and reduce refrigerant emissions.

EE impact from indirect emission

79. There are several methodologies that estimate the total emissions from a system. Most common are Total Equivalent Warming Impact (TEWI)[51] and Life Cycle Climate Performance (LCCP) which attempts to quantify the total global warming impact by evaluating the RACHP systems during their lifetime from “cradle to grave”.

80. The largest potential for EE improvement comes from improvements in design and components, which can yield efficiency improvements[52] of 10 to 70 per cent compared with 5-10 per cent for the refrigerant in most cases. Calculating lifecycle emissions at the country or regional level would require

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[50] This is in the context of the phase-down of HFCs.

[51] Sometimes, a TEWI calculation may be simplified by neglecting broader effects including manufacture of the refrigerant and equipment, and disposal of the refrigerant and equipment after decommissioning. The impact of these components could be small.

[52] When EE improvements are referred to in this report we compare the energy used by an improved design to a baseline design. For example, if system A uses 10 units of energy and system B uses 8 units, there is a 20 per cent efficiency improvement.

several steps and assumptions, such as product lifetime, refrigerant choice and leakage, that extend beyond considerations of the environmental benefits from EE. The environmental benefits from EE can vary by a factor of 1,000 depending on the hours of use and the emissions factor for electricity generation.

81. Calculating the environmental benefits of EE in RACHP equipment in CO_2-eq terms involves the following three steps:

(a) Determine the type of equipment (e.g., ductless split air-conditioner, 3.5 kW cooling capacity), identify the baseline model unit energy consumption as a function of the current market in the country or territory or the units manufactured by a given facility, and determine the EE improvement to be evaluated;

(b) Calculate the energy savings for the higher efficiency model as a function of baseline unit energy consumption and hours of use. Hours of use vary significantly by country and climate and application; in some cases, national standards define the hours of use as part of the EE metric (for example, the India Seasonal Energy Efficiency Ratio is defined using 1,600 hours of use annually). Actual energy performance of installed equipment may be lower than the designed efficiency due to poor installation or maintenance. Since the efficiency improvement is compared to a baseline unit, this approach assumes that performance degradation due to poor installation or maintenance or high temperatures would have a comparable effect on the baseline unit, so the relative energy savings are maintained. If hours of use increase in the case of the higher efficiency unit due to lower electricity bill costs, a form of rebound behaviour, the energy savings would be reduced due to “rebound” effect; and

(c) Convert energy savings to CO_2-eq by multiplying by the end-use emission factor for electricity generation. Air-conditioners tend to run during the hottest times of day, and tend to coincide with peak electricity demand; for this reason, use of “marginal emission” factors, which represent the carbon intensity of the generators that produce power to meet peak demand, may be more accurate. Whether the carbon intensity of marginal generation is higher or lower than the annual emission factor depends on the grid composition of the country. However, as more renewable capacity is added, the trend is towards lower marginal emissions factors.

82. In the domestic refrigeration sector, savings due to EE appliances range from 55 per cent to nearly 70 per cent with technologies that are presently available. It is assumed in this case that refrigerators operate 24 hours per day and that HAT do not impact the performance of the devices, as they are placed indoor in environments with controlled temperature.

83. In case of commercial refrigeration, there is a very high energy saving potential. In some cases, as in open- versus closed-door freezers and coolers, savings can range from 70 to 80 per cent. In the case of ice cream freezers, the energy consumption was measured at 25°C and 31°C. The energy consumption increased 13 per cent at the higher ambient condition. However, the energy consumption was still much lower than an inefficient, vertical freezer. This shows that also in HAT conditions, the choice of the device is crucial.

84. Table 8 presents the summary of energy savings in kWh per year for specified hours of use of room air-conditioners and EE at the specified product EE level (higher efficiency level at 10-20 per cent and highest efficiency level 40-50 per cent compared to base unit energy use).

Table 8. Energy savings for a room air-conditioners unit

Case*	Identify product-specific baseline unit energy consumption and efficiency improvement					Calculate per unit energy savings for efficient models	
	Hours of use/year	Unit type /cooling capacity (kW)	Base air-conditioners unit energy use (kWh/yr)	Higher EE	Highest EE	Higher EE (kWh/yr)	Highest EE (kWh/yr)
Very low case **a** (very low hours, very low electricity emission factor)	350	Split unit / 3-4 kW	266	20 per cent	50 per cent	53	133
Low case **b** (low hours, low electricity emission factor)	1,200	Split unit / 3.5 kW	1,355	20 per cent	50 per cent	271	678
High hours **c** (high hours, middle electricity emission factor)	2,880	Split unit / 3.5 kW	2,965	10 per cent	40 per cent	297	1186
High emission factor **d** (middle hours, high electricity emission factor)	1,600	Split unit / 5.275 kW	1,300	10 per cent	40 per cent	130	520
Highest case **e** (high hours, high electricity emission factor)	2,880	Split unit / 5.275 kW	5,759	25 per cent	40 per cent	1,440	2,304

(*) The five cases representing the situations that can be found in the actual scenario of climate zones and emission factors throughout the world.[53]

a Hours of use for cooling in Europe (Topten.eu); unit energy use from Topten.eu with inefficient (266 kWh/yr) and highest efficiency (122 kWh/yr).

b Hours of use and base air-conditioner unit energy consumption from United for Efficiency Country Assessment for Argentina (December 2016); percent improvement based on Topten.eu.

c Hours of use and base air-conditioner unit energy consumption from United for Efficiency Country Assessment for Thailand (December 2016); percent improvement based on India BEE 3-star and 5-star examples; emission factor for Thailand.

d Hours of use and base air-conditioner unit energy consumption from Indian ISEER standard and BEE 1-star level; percent improvement based on India BEE 3-star and 5-star examples.

e Hours of use for 8 hours for 360 days; base unit 2.6 W/W EER converted to energy consumption by dividing capacity by EER times hours of use; mid = 3.5 EER and highest = 4.5 EER.

85. In case of heat pumps, the energy savings for a heat pump unit in four cases representing the situations that can be found in the actual scenario of climate zones throughout the world is given in Table 9.

Table 9. Energy savings for a heat pump unit

Case*	Unit energy consumption								EE impro-vement (%)
	Base case				Best available technology (BAT)				
	Heat pump (GJ)	Electric backup (GJ)	Total (GJ)	Total (kWh/y)	Heat pump (GJ)	Electric backup (GJ)	Total (GJ)	Total (kWh/y)	
Cold climate and low emission factor	12.31	7.97	20.28	5,633	12.62	2.6	15.22	4,228	25

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[53] CO_2 emission impact is provided in the TEAP task force report.

Case*	Unit energy consumption								EE improvement (%)
	Base case				Best available technology (BAT)				
	Heat pump (GJ)	Electric backup (GJ)	Total (GJ)	Total (kWh/y)	Heat pump (GJ)	Electric backup (GJ)	Total (GJ)	Total (kWh/y)	
Cold climate and medium emission factor	12.31	7.97	20.28	5,633	12.62	2.6	15.22	4,228	25
Warm climate and medium emission factor	3.23	0.336	3.566	991	2.95	0.104	3.054	848	14
Mild climate and high emission factor	8.08	2.48	10.56	2,933	6.42	0.4	6.82	1,894	35

(*) The four cases representing the situations that can be found in the actual scenario of climate zones and emission factors throughout the world.[54]

86. In case of mobile AC, based on a report on some passenger vehicle fuel economy standards that includes credits for high-efficiency AC, the GHG emission impact is identified as an indicator of the potential benefits and the range is from 0.9 grams CO_2-eq/km to 6.1 grams CO_2-eq/km.

VI. DEMONSTRATION PROJECTS FOR THE INTRODUCTION OF LOW-GWP TECHNOLOGIES AND HFC STAND-ALONE INVESTMENT PROJECTS

87. At its 74th, 75th and 76th meetings, the Executive Committee approved three feasibility studies for district cooling)[55] and 17 projects to demonstrate low-GWP technologies pursuant to decision XXV/5 and decision 72/40.[56]

88. Table 10 summarizes information on energy efficiency based on results available from the demonstration projects approved in line with decision 72/40, excluding refrigeration servicing sector projects.

Table 10: Feasibility studies and demonstration projects for the introduction of low-GWP technologies

Country	Project title (code)	Funding (US $)*	Meeting	Update on the progress in implementation
Refrigeration and AC and assembly sub-sector				
China	Demonstration project for ammonia semi-hermetic frequency convertible screw refrigeration compression unit in the industrial and commercial refrigeration industry at Fujian Snowman Co. Ltd. (CPR/REF/76/DEM/573)	1,026,815	82	The report mentioned that COP[57] of the new system designed in the project having refrigeration capacity of 56.7 kW, 167.1 kW and 216.3 kW systems is 1.57, 1.63 and 2.94, respectively.

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[54] CO_2 emission impact is provided in the TEAP report. The information given in gigajoules (GJ) relates to annual consumption.

[55] The Dominican Republic, Egypt, and Kuwait.

[56] Including: seven projects in the refrigeration and AC and assembly sub sector (China, Colombia, Costa Rica, Kuwait, Saudi Arabia (two), a global (Argentina and Tunisia) and a regional (West Asia) project; six in the foam sector (Colombia, Egypt, Morocco, Saudi Arabia, South Africa, and Thailand); and three in the refrigeration servicing sector (Maldives, Europe and Central Asia region, and a global project (Eastern Africa and Caribbean regions).

[57] COP – Coefficient of Performance.

Country	Project title (code)	Funding (US $)*	Meeting	Update on the progress in implementation
Colombia	Demonstration of R-290 (propane) as an alternative refrigerant in commercial AC manufacturing at Industrias Thermotar ltd (COL/REF/75/DEM/97)	500,000	81	The report mentions that an R-290 5-TR[58] split unit equipment (R-290 scroll compressor) consumes 13.1% less energy (kWh) than a similar R-410A unit.
Costa Rica	Demonstration of the application of an ammonia/carbon dioxide refrigeration system in replacement of HCFC-22 for the medium-sized producer and retail store of Premezclas Industriales S.A. (COS/REF/76/DEM/55)	524,000	82	The final report indicated that comparison of average monthly bills for October / November 2017 (prior to installation of the new refrigeration system) and January / February 2018 (after installation of new refrigeration system) shows that the average monthly bills decreased by 10.23 per cent. This consumption decrease was expected to grow after system is stabilised and better operations practices to about 20 per cent.
Saudi Arabia	Demonstration project at AC manufacturers to develop window and packaged air-conditioners using low-GWP refrigerants (SAU/REF/76/DEM/29)	1,300,000	83	The results of demonstration projects show higher EER of HFC-32 and R-290 compared to R-410A at 52 degrees centigrade; EER decreases for all refrigerants when the outdoor temperature increases from 35 to 52 degrees centigrade.
Saudi Arabia	Demonstration project on promoting HFO-based low-GWP refrigerants for AC sector in high ambient temperatures (SAU/REF/76/DEM/28)	796,400	Not available	Final report is expected to be submitted to the 85th meeting.
Regional (West Asia), PRAHA-II	Promoting alternative refrigerants in AC for high ambient countries in West Asia (PRAHA-II) (ASP/REF/76/DEM/59 and 60)	700,000	Not available	Final report is expected to be submitted to the 84th meeting.
Foam sector				
Colombia	Demonstration project to validate the use of hydrofluoro-olefins for discontinuous panels in Article 5 parties through the development of cost-effective formulations (COL/FOA/76/DEM/100)	248,380	81	Results on energy efficiency were not directly reported; however, results show thermal conductivity levels for formulations using HFO-1233zd(E) and HFO-1336mzz(Z) co-blown with water were similar to HCFC-141b based formulations.
Egypt	Demonstration of low-cost options for the conversion to non-ODS technologies in polyurethane foams at very small users (EGY/FOA/76/DEM/129)	295,000	83	The report did not provide information on energy efficiency of the equipment. Updated report has been submitted to the 84th meeting.
Morocco	Demonstration of the use of low cost pentane foaming	280,500	Not available	

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[58] TR – Tonne of Refrigeration.

Country	Project title (code)	Funding (US $)*	Meeting	Update on the progress in implementation
	technology for the conversion to non-ODS technologies in polyurethane foams at small-and medium-sized enterprises (MOR/FOA/75/DEM/74)			
Saudi Arabia	Demonstration project for the phase-out of HCFCs by using HFO as foam blowing agent in the spray foam applications in high ambient temperatures (SAU/FOA/76/DEM/27)	96,250	Not available	Final report is expected to be submitted to the 84th meeting.
South Africa	Demonstration project on the technical and economic advantages of the vacuum assisted injection in discontinuous panels plant retrofitted from HCFC-141b to pentane (SOA/FOA/76/DEM/09)	222,200	81	Results on energy efficiency were not directly reported; however, results show thermal conductivity levels comparable to HCFC-141b.
Thailand	Demonstration project at foam system houses to formulate pre-blended polyol for spray polyurethane foam applications using low-GWP blowing agent (THA/FOA/76/DEM/168)	352,550	83	Results on energy efficiency were not directly reported; however, results show thermal conductivity levels for formulations using HFO-1233zd(E) and HFO-1336mzz(Z) co-blown with water had marginally higher thermal conductivity. This could change with improvements in the formulations.
Feasibility study for district cooling				
The Dominican Republic	Feasibility study for district cooling in Punta Cana (DOM/REF/74/TAS/57)	91,743	81	Energy efficiency was a key benefit from the project; Actual energy efficiency performance gains is not available.**
Egypt	Feasibility study for district cooling in New Cairo (EGY/REF/75/TAS/127 and 128)	27,223	82	The reports contain techno-economic feasibility of the district cooling configurations and return calculations. Actual energy efficiency performance gains is not available.**
Kuwait	Feasibility study comparing three not-in-kind technologies for use in central AC (KUW/REF/75/TAS/28 and 29)	27,223	82	The reports contain techno-economic feasibility of the district cooling configurations and return calculations. Actual energy efficiency performance gains is not available.**

* This value does not include project preparation fund and agency support cost.

** TEAP task force report mentions that district cooling systems reduce power demand by 55 to 62 per cent in comparison to conventional AC systems and consume 40 to 50 per cent less energy

89. Table 11 lists the ten stand-alone HFC investment projects so far approved. While the report on energy efficiency performance of the redesigned equipment is required in the final report, the results of these projects is not available as of date.

Table 11. Stand-alone HFC investment projects so far approved

Country	Agency	Project title
Argentina	UNIDO	Conversion project for replacement of HFC-134a with isobutane (R-600a)/propane (R-290)-based refrigerant in the manufacture of domestic and commercial refrigeration equipment at Briket, Bambi and Mabe-Kronen
Bangladesh	UNDP	Conversion from HFC-134a to isobutane as refrigerant in manufacturing household refrigerator and of reciprocating compressor of HFC-134a to energy efficient compressor (isobutane) in Walton Hi-Tech Industries Limited
China	UNDP	Conversion from C5+HFC-245fa to C5+HFOs in a domestic refrigerator manufacturer (Hisense Kelon)
Dominican Republic (the)	UNDP/Canada	Conversion of a commercial refrigerator manufacturing line at Fábrica de Refrigeradores Comerciales, SRL (FARCO) from HFC-134a and R-404A to propane (R-290) as refrigerant
Jordan	UNIDO	Conversion of large commercial unitary roof top AC units of up to 400kW manufacturing facility from HFC (R134a, R-407C, R-410A) to propane R290 as refrigerant at Petra Engineering Industries Co.
Lebanon	UNIDO	Conversion from HFC-134a and HFC-404A to R-600a and R-290 in domestic refrigeration at Lematic Industries
Mexico	UNIDO	Conversion of commercial refrigeration manufacturing in two facilities from the use of HFC-134a and R-404A as the refrigerants to propane (R-290) and isobutane (R-600a) at Imbera
Mexico	UNDP/Canada	Conversion of domestic refrigeration manufacturing facility from HFC-134a to isobutane as a refrigerant and conversion of compressors manufacturing facility from HFC-134a-based to isobutane-based at Mabe Mexico
Thailand	IBRD	Conversion from HFC to propane (R-290) and isobutene (R-600a) as a refrigerant in manufacturing commercial refrigeration appliances in Pattana Intercool Co. Ltd.
Zimbabwe	UNDP/ France	Conversion from HFC-134a to isobutane in the manufacture of domestic refrigerators at Capri (SME Harare)

Recommendation

90. The Executive Committee may wish to consider the updated summary of the report by the Technology and Economic Assessment Panel on matters related to energy efficiency with regard to the issues identified in decision 82/83(e) (decision 83/64) contained in document UNEP/OzL.Pro/ExCom/84/69 during its deliberations relating to ways to operationalize paragraph 22 of decision XXVIII/2, and paragraphs 5 and 6 of decision XXX/5.

Annex I

GLOSSARY OF TERMS USED IN THE PRESENT DOCUMENT

APF: Annual Performance Factor (see Seasonal Energy Efficiency Ratio)

Coefficient of performance (COP, sometimes CP or CoP): For a heat pump, refrigerator or AC system, this is a ratio of useful heating or cooling provided to work required. Higher COPs equate to lower operating costs.

Cooling capacity: A measure of a system's ability to remove heat. Measured in kW, Btu/h, or refrigeration ton (RT), where 1 RT = 3.5 kW = 12,000 Btu/h.

Cooling/heating load: The amount of energy needed to heat or cool to a desired level of service. Improving insulation in a building is a strategy for reducing heating and cooling load while providing the same level of comfort to the occupant.

Coefficient of Performance (COP): COP is defined as the ratio between the cooling capacity and the power consumed by the system. COP is also used for heat pumps and in this case it is defined as the ratio between the heating capacity and the power consumed by the system.

CSPF: Cooling season performance factor (see Seasonal Energy Efficiency Ratio).

Design efficiency: The energy performance of equipment as designed or as shipped, same as nameplate efficiency.

Energy Efficiency (EE): Energy efficiency is an attribute of a device or process, which can be either high or low.

Energy Efficiency Ratio (EER): Ratio of the cooling output divided by the electrical energy input when measured at full load (i.e., at the maximum cooling capacity or the design point) and is measured in W/W or Btu/h/W (1 W = 3.412 Btu/h).

Energy performance: The amount of energy consumed for a piece of equipment or system to perform a specific level of service. EE improvements referred to in this report, compare the energy used by an improved design to a baseline design. For example, if System A uses 10 units of energy and System B uses 8 units, there is a 20 per cent efficiency improvement.

HSPF: Heating Seasonal Performance Factor (see Seasonal Energy Efficiency Ratio)

Installed efficiency: The energy performance of equipment as installed.

ISEER: Indian Seasonal Energy Efficiency Ratio.

Kilowatt-hour (kWh): A measure of electricity defined as a unit of work or energy, measured as 1 kilowatt (1,000 watts) of power expended for 1 hour. One kWh is equivalent to 3,412 British Thermal Units (Btu) or 3.6 MJ.

Manufacturing cost: cost to manufacture the equipment.

Million tonnes oil equivalent (Mtoe): 1 Mtoe = 11.63 billion kWh.

Nominal design point: represents the set of conditions (e.g. indoor and outdoor temperatures) used to design the system.

Operating cost: The cost to the equipment user to operate the equipment.

Part-load operation: condition that happens when the system has to face a load lower than nominal (nominal conditions are used for the design of the system). RACHP systems usually operate at part-load conditions for most part of their life cycle.

Peak Load: The highest electricity demand occurring within a given period on an electric grid.

Percent energy efficiency improvement: percent change in energy consumption of an efficient unit compared with a base unit.

Refrigeration Ton (RT): Measure of cooling capacity, where 1 ton refers to 12,000 Btu, equivalent to the energy required to freeze 2000 pounds of water in 24 hours. 1 RT = 3.52 KW.

Retail price: Price to purchase the equipment.

Seasonal Energy Efficiency Ratio (SEER): Ratio of cooling output divided by the electrical energy input, measured at full and part-load, and weighted to represent the overall performance of the device for the weather over a typical cooling season in each given country. An alternative name to SEER is the **Cooling Seasonal Performance Factor (CSPF)**. **Heating Seasonal Performance Factor (HSPF)** is used for heating mode. **Annual Performance Factor (APF)** is a metric used for reversible heat-pump room air-conditioners that heat and cool.

Unit energy consumption: The amount of energy consumed by a unit of equipment, usually over one year.

Variable speed drives (VSD): A type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor, also known as inverter.

Annex II

AVAILABILITY OF AIR-CONDITIONERS OPERATING WITH DIFFERENT REFRIGERANTS AND AT DIFFERENT EE LEVELS

Table 1: Availability of technology options for AC: Energy Efficiency vs. refrigerants - Low Tier

Low Tier Energy Efficiency Meeting MEPS	**Regions**	**HCFC**	**High-GWP HFC**	**Medium and low GWP**
	Australia & New Zealand (ANZ)	Aus. & NZ: Not Available	**45% of the market is R-410A in the low and mid-tier efficiency ranges**	**53% of the market is HFC-32 units more weighted towards the higher efficiency tiers 1% of the market is HC-290 in the low tier**
	Oceania & PIC	**Around 5% of the market**	**Papua New Guinea / Fiji/ Solomon Islands: R-410A imports from ANZ in the low and mid tiers**	**HFC-32 becoming prevalent in line with trend in ANZ**
	Japan	Japan: Not Available	**Japan: Units available for export only Regulation does not support equipment development with high-GWP HFCs**	**Japan: HFC-32 units are prevalent**
	Korea	Korea: Not Available	**Korea: 410A system including ductless, mini-split system and VRF**	**Korea: HFC-32**
	China	**China: Less than 20% equipment with HCFCs**	**China: about 60% of equipment are High-GWP HFCs**	**China: HFC-32 and HC-290 units are available**
	Thailand	**Locally manufactured**	**R-410A locally manufactured with inverter and non-inverter**	HFC-32 units locally manufactured in small quantities
	South East Asia	**Locally manufactured in some countries**	**Indonesia: ~50 of the market is R-410A R-410A fixed speed locally manufactured in some countries or imported MEPS are not separated for inverter and non-inverter except in Singapore and Indonesia**	Malaysia: manufacturing of compressors for HFC-32 Vietnam and Indonesia: HFC-32 units with inverter
	India	**India: Available from local manufacturers. Import is not allowed.**	India: Not available in lower efficiencies	**India: HFC-32 and HC-290 units available**
	Central Asia	**Locally manufactured in some countries**	**Locally manufactured in some countries**	Available for import
	Gulf Cooperation Council	**Available as locally manufactured or imported**	**HAT: R-410A with fixed speed and variable speed**	HFC-32 units are available Research on HC-290 and HFO leads to viable result Saudi G-Mark regulation requires certification for charge limitation of flammable refrigerants for residential applications

	Middle East & North Africa	**Available as locally manufactured or imported**	**Available as locally manufactured or imported**	HFC-32 and R-454B Accepted in Egypt, manufacturing not started Morocco*: HFC-32 inverter is available for import through Buyers' club
	Central Africa	**Available in most countries**	**R-410A units fixed speed and inverter**	Ghana: HC-290 units imported into the country in a program supported by GIZ Other countries: HFC-32 units with inverter available for import*
	Southern Africa	**Available as locally manufactured or imported**	**R-410A units fixed speed and inverter**	HFC-32 units
	Europe		**EU: Available in R-410A and R-407C in mini-splits: 2-speed and VRF**	**EU: both HFC-32 and HC-290**
	North America		**N. America: Available in R-410A and R-407C in mini-splits: 2-speed and VRF**	*N. America: Emerging new technology using HFC-32 and HFO blends*
	Central America	**Available in most countries**	**R-410A available**	Mexico: HFC-32 inverter by at least one manufacturer Other countries: HFC-32 available to import Grenada: HC-290 available to import through a GIZ program
	South America	**Available in most countries**	**S. America: R-410A both fixed speed and variable speed** **Brazil: 40-50% of R-410A units are inverter**	Brazil: HFC-32 inverter available from one manufacturer. A second manufacturer announced production of HFC-32 by end of 2019 HC-290 expected to be available once MLF projects completed. Other countries: available to import

Table 2: Availability of Technology for AC: Energy Efficiency vs. refrigerants - Mid Tier

Mid-Tier Energy Efficiency up to 10% above Minimum MEPS	Regions	HCFC	High-GWP HFC	Medium and low GWP
	Australia & New Zealand	Aus. & NZ: Not Available	**45% of the market is R-410A in the low and mid-tier efficiency ranges**	**53% of the market is HFC-32 units more weighted towards the higher efficiency tiers**
	Oceania & PIC	**Around 5% of the market**	**Papua New Guinea / Fiji/ Solomon Islands: R-410A imports from ANZ in the low and mid tiers**	**HFC-32 becoming prevalent in line with trend in ANZ**
	Japan	Japan: Not Available	Japan: Not Available	**Japan: "The top runner program" requires weighted average APF higher than the standard value. (for both domestic and commercial air-conditioners)**
	Korea	Korea: Not Available	**Korea: 410A system including ductless, mini-split system and VRF**	**Korea: HFC-32 units with inverter**
	China	**China: Less than 20% equipment with HCFCs**	**China: about 60% of equipment are High-GWP HFCs**	China: Both HC-290 and HFC-32 inverter that have higher APF than the standard value are introduced
	Thailand	**Thailand: Locally manufactured**	**Thailand: R-410A locally manufactured**	**Thailand: 70% of the locally manufactured units are HFC-32 units with inverter**
	South East Asia	**Locally manufactured in some countries**	**Indonesia: 5% of the market is R-410A inverter R-410A units are locally manufactured in some countries or imported MEPS are not separated for inverter and non-inverter except in Singapore and Indonesia**	**Indonesia: ~ 50% of the market is HFC-32 units MEPS are not separated for inverter and non-inverter except in Singapore and Indonesia**
	India	**India: Available from local manufacturers. Import is not allowed.**	**India: R-410A widely available up to 3 Stars**	**India: HFC-32 and HC-290 available up to 5 Star**
	Central Asia	**Locally manufactured in some countries**	**Locally manufactured in some countries**	Available for import
	Gulf Cooperation Council	**Available as locally manufactured or imported**	**R-410A with inverter**	HFC-32 units are available Research on HC-290 and HFO leads to viable results Saudi G-Mark regulation requires certification for charge limitation of flammable refrigerants for residential applications
	Middle East & North Africa	**Available as locally manufactured or imported**	**Available as locally manufactured or imported**	HFC-32 and R-454B Accepted in Egypt, manufacturing not started Morocco: HFC-32 inverter is available for import
	Central Africa	Not Available	**R-410A units with inverter**	HFC-32 units in some markets
	Southern Africa	Not Available	**R-410A units with inverter South Africa: 75% of the market is inverter**	HFC-32 units in some markets
	Europe	Not Available	**EU: Available in R-410A and R-407C in mini-splits: 2-speed and VRF**	**EU: Cent A/C 2-speed, Mini-splits VRF - EU Eco-Design,**

	North America	Not Available	**N. America: Available in R-410A and R-407C in mini-splits: 2-speed and VRF**	*N. America: Emerging new technology using HFC-32 and HFO blends*
	Central America	**Available in most countries**	**R-410A available**	Mexico: HFC-32 inverter by at least one manufacturer
	South America	**Available in most countries**	**S. America: R-410A both fixed speed and variable speed** **Brazil: 40-50% of R-410A units are inverter**	Brazil: HFC-32 inverter available from one manufacturer. A second manufacturer announced production of HFC-32 by end of 2019 HC-290 expected to be available once MLF projects completed. Other countries: available to import

Table 3: Availability of Technology for AC: Energy Efficiency vs. refrigerants - High Tier

High Tier Energy Efficiency more than 10% above Minimum MEPS	**Regions**	**HCFC**	**High-GWP HFC**	**Medium and low GWP**
	Australia & New Zealand	Not Available	Not Available	**53% of the market is HFC-32 units more weighted towards the higher efficiency tiers**
	Oceania & PIC		Not Available	Available for import
	Japan		Japan: Not Available	**Japan: "The top runner program" requires weighted average APF higher than the standard value (for both domestic and commercial air-conditioners)**
	Korea		**Korea: 410A system including ductless, mini-split system and VRF**	**HFC-32 units with inverter**
	China		**China: "The top runner program" requires weighted average APF higher than standard value, about 1% of market**	China: Both HC-290 and HFC-32 inverter that have higher APF than the standard value are introduced
	Thailand		**R-410A locally manufactured mainly inverter type Separated MEPS for inverter and non-inverter**	**HFC-32 units with inverter Separated MEPS for inverter and non-inverter**
	South East Asia		**R-410A locally manufactured in some countries or imported. MEPS are not separated for inverter and non-inverter except in Singapore and Indonesia**	**Indonesia, Philippines, and Vietnam: HFC-32 units with inverter**
	India		**India: R-410A widely available in inverter 3 to 5 star**	**India: HFC-32 and HC-290 available up to 5 Star**
	Central Asia		Available for import	Available for import
	Gulf Cooperation Council		HAT: High GWP HFCs Could not meet higher efficiency with conventional design, however, MEPS >10%, (EER 12.7) can be achieved with microchannel heat exchangers	HFC-32 units are available Research on HC-290 and HFO leads to viable result Saudi G-Mark regulation requires certification for charge limitation of flammable refrigerants for residential applications
	Middle East & North Africa		**Available as locally manufactured or imported**	HFC-32 and R-454B Accepted in Egypt, manufacturing not started. Morocco: HFC-32 inverter is available for import
	Central Africa		**R-410A units with inverter**	HFC-32 units in some markets
	Southern Africa		**R-410A units with inverter South Africa: 75% of the market is inverter**	HFC-32 units in some markets
	Europe		**EU: Cent A/C 2-speed, Mini-splits, VRF- Eco-Design**	**EU: Cent A/C 2-speed, Mini-splits VRF - EU Ecodesign**
	North America		**N. America: Cent A/C 2-speed, Mini-splits, VRF with R-410A units**	*N. America: Emerging new technology using HFC-32 and HFO blends*
	Central America		**R-410A available**	Mexico: HFC-32 inverter by at least one manufacturer
	South America		**S. America: R-410A both fixed speed and variable speed Brazil: 40-50% of R-410A units are inverter**	Brazil: HFC-32 inverter available from one manufacturer. A second manufacturer announced production of HFC-32 by end of 2019. HC-290 expected to be available once MLF projects completed. Other countries: available to import

Annex III

INFORMATION ON AVAILABILITY, COST AND ENERGY EFFICIENCY (EE) IMPACT AND APPLICATION TO CLIMATE REGION FOR DIFFERENT COMPONENTS RELATED TO EE FOR MEDIUM- AND LOW-GLOBAL-WARMING POTENTIAL REFRIGERANTS FOR AIR-CONDITIONERS AND SELF-CONTAINED COMMERCIAL REFRIGERATION EQUIPMENT

Part 1: Air conditioners

Component	Applicable to ref circuit	Available today?	Presently in use?	Remarks	Necessary components	Max potential improvement	Incremental cost for RAC unit	Applicability to climate region		
								LAT	MAT	HAT
Compressors										
Higher efficiency	X	Y	Y	Mostly rotary compressor				X	X	X
-Inverter driven	X	Y	Y	Mostly used for rotary	Inverter, dedicated compressor	20% to 30%	20%	X	X	X
- two stage compression	X	Y	L	Very limited availability		10%	10% – 20%	X	X	X
- motor efficiency controllers		Y	L	Standard		same	Same	X	X	X
Energy efficient fan motors										
- EC fan motors		Y	Y	Reduce energy, heat load	Controller	7% to 15%	15% to 25%	X	X	X
- variable/fixed-speed		Y	Y					X	X	X
- optimized fan blades		Y	Y					X	X	X
-tangential fans		Y	Y	For indoor unit only				X	X	X
- improved axial fans		Y	Y	For outdoor unit only				X	X	X
Expansion devices										
- electronic expansion valves	X	Y	L		EEV and controller	15% to 20%	15%	X	X	X
-fixed orifice	X	Y	L		RAC heating	Less efficiency	negative	X	X	X
- capillary tubes	X	Y	Y		TEV	Heating mode	negative	X	X	X
Heat exchangers										
-Microchannel condenser coil	Y	Y	Y	Only condenser	AL/AL	15%	negative	X	X	X
-Microchannel evaporator coil	N	N	N				Less cost compared to the fin and tube			
- smaller tube diameter for condenser coil	X	Y	Y	Y	CU/AL	10% to 40%,	negative	X	X	X
- smaller tube diameter for evaporator coil		Y	Y	Y	CU/AL	10% to 40%	negative	X	X	X
Adiabatic condensers		Y	Very limited	Only in high ambient	Filter and water treatment	25% to 30%	20% to 35%			X
Pipe insulation		Y	Y	Normal practice	Pipe insulation	<2%	Standard	X	X	X
Refrigerant	X	Y	Y	See RTOC 2014, 2018	Refrigerant	See RTOC 2014, 2018	+/- depends on the region	X	X	X

Component	Applicable to ref circuit	Available today?	Presently in use?	Remarks	Necessary components	Max potential improvement	Incremental cost for RAC unit	Applicability to climate region		
								LAT	MAT	HAT
Defrost techniques	Y	Y		For HP only	controller		HP	X	X	X
- hot gas, reverse cycle		Y	L	HP	4 WAY VALVE	negative	Heating	X	X	X
- resistance heaters for Heating		Y	Y	some regions	Electric heater	negative	Some areas	X	X	X
- on demand control		Y	Y		controller		same	X	X	X
Controls										
- dynamic demand controllers		Y	Y		standard		standard	X	X	X
Reducing head pressure	X	Y	Y		Var speed cond. fans, controller	2 – 3% per 1 K	various		X	X

Part 2: SCCRE

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
Anti-fogging glass		Y	Y	Glass door freezer	Avoids heating elements, as option	Surface treatments	Minimal	<5%		X	X
Improved cabinet air flow											
- air deflectors/guides		Y	Y	Open multideck	Reduces cold spillage	Aerofoils	15%	neg.	X	X	X
- shelf risers and weir plates		Y	Y	Open multideck	Reduces cold spillage	Plastic strips	4%	neg.	X	X	X
- short air curtains		Y	Y	Open multideck	Reduces cold spillage	Airflow design	30%	neg.	X	X	X
- strip/night curtains		Y	Y	Open multideck	Reduces cold spillage	Clear plastic strips	60%	$100	X	X	X
Energy efficient fan/motors											
- Electronically Communicated (EC) fan motors		Y	Y	All types	Less energy & heat load	EC motors	10%	+15%	X	X	X
- variable speed		Y	Y	All types	e.g., 2-speed fixed	Fan motor type	10%	+15%	X	X	X
- optimised fan blades		Y	Y	All types	Match press of cabinet	None	5%	Neg.	X	X	X
- tangential fans		Y	Y	All types		Fan type	5%	<10%	X	X	X
- diagonal compact fans		Y	Y	All types		Fan type	5%	<10%	X	X	X

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
- improved axial fans		Y	Y	All types		Fan type	5%	<10%	X	X	X
- fan motor outside cabinet		Y	N	Never used	Not worth it	None	n/k	neg.	X	X	X
Cabinet doors											
- doors on cabinets		Y	Y	All types	Reduces heat load and infiltration	Doors	45%	$300 per m	X	X	X
- door gaskets		Y	Y	Standard for freezer	Reduces heat load and infiltration	Gaskets	15%	$30	X	X	X
Compressors											
- higher efficiency	X	Y	Y	All types	Increased by 20% over past 20 years	Advanced compressor	20% (MT), 30% (LT)	neg.	X	X	X
- Inverter driven	X	Y	Y	All types	Better PL efficiency; with/out PFC	Inverter, dedicated compressor	40%	2 × non-inverter	X	X	X
- motor efficiency controllers		Y	L	All types	Regions having poor mains power; not needed for Variable Speed Drive (VSD)	MEC device	10%	n/k	X	X	X
- two stage compression	X	Y	L	Mainly for R744		Two (smaller) compr; two roller rotaries	5%	20 – 40%	X	X	X
- economisers / inter-stage coolers	X	Y	L	Mainly for R744		Special compressor + flash vessel or HX	15%	n/k	X	X	X
Expanders	X	Y	L	Mainly for R744		Expander / integrated compressor-expander	30%	n/a	X	X	X
Cabinet lighting											
- LEDs		Y	Y	All types	Now standard	LED lamps	50% on lighting	<0%	X	X	X
- occupancy sensors		Y	Y	mainly for non-perishables	On demand lighting	Proximity sensors	10%	<0%	X	X	X
Defrost techniques											
- hot gas, reverse cycle		Y	L	Freezers, shortens time, product quality	Increases leaks, faults	Valve	5%	3%	X	X	X

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
- resistance heaters		Y	Y	MT and LT cabinets[1]	Preferred / reliable	Heater rods	n/a	n/a	X	X	X
- off-cycle		Y	Y	HT and MT cabinets	Eliminates defrost energy	none	10%	<0%	X	X	X
- on demand control		Y	Y	All types	Defrosts when needed	Sensors, controller	10%	<5%	X	X	X
Controls											
- dual port thermostatic expansion valve (TEV) (balanced)	X	Y	N	Open type	Evens evaporator load	TEV	n/k	n/k	X	X	X
- dynamic demand controllers		Y	Y	All types	Manages energy use	Sensors & controller	40%	Various	X	X	X
- electronic expansion valves (EEV)	X	Y	L	Larger cabinets	Modulates evaporator pressure	EEV and controller	20%	$200	X	X	X
- optimisation of capillary	X	Y	Y	All cabinets			Anything	Neg.	X	X	X
- suction pressure control	X	Y	L	Larger systems	Modulates evaporator pressure	(See VSC & EEV)	2% per K increase	$40 - $400	X	X	X
Reducing head pressure	X	Y	Y	Larger systems	Reduces press lift	Variable speed fans, controller	2 – 4% per 1 K reduction	Various		X	X
Ejectors	X	Y	L	Larger systems, R744 only		Ejector valve	20% or 30% with R744	$20		X	X
Heat exchanger (HX) design											
- optimised configuration	X	Y	Y	All types	Better heat transfer (HT), lower discharge pressure (DP)	HX materials	0 to 40% of baseline	Neg	X	X	X
- optimised air fins		Y	Y	All types	Better HT, lower DP	HX design	10%	Neg	X	X	X
- internal rifling	X	Y	Y	All types	Better HT, lower DP	HX design	5%	Neg	X	X	X
- internal fins	X	Y	Y	All types	Better HT, lower DP	Internal fins	5%	Neg	X	X	X
- hydrophobic coating		Y	L	All types	Mainly for conds, reduces dust and corrosion	Coating	5%	Neg	X	X	X

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[1] LT: Low Temperature, around -18°C; MT: Medium Temperature, around 0°C to 8°C

Option	Applicable to ref circuit	Available today?	Presently in use?	Applicable to what SCCRE?	Remarks	Necessary component(s)	Max potential EE improvement of entire SCCRE	Indicative additional cost for SCCRE	Applicability to climate region		
									LAT	MAT	HAT
- hydrophilic coating		Y	L	All types, evaporators	Anti-corrosion; reduce water layer thickness	Coating	5%	Neg	X	X	X
- flooded evaporators	X	Y	N	Larger systems	added to R744	Float v, surge drum	5%	n/a	X	X	X
Other heat load											
- radiant reflectors		Y	Y	Any glass	Reflects infrared (IR)	Internal surface	8%	Neg	X	X	X
- night blinds and covers		Y	Y	All types	Can reduce IR and infiltration	Night blinds, covers	20%	$300	X	X	X
- improved glazing		Y	Y	Any glass	Reflects IR	New glass	5%	5%	X	X	X
- anti-sweat heater control		Y	Y	Any with AS heaters	Minimise heat load	Controller, sensors	3%	Neg.	X	X	X
- refrigerant line trim heaters		Y	Y	LT cabinets	Instead of resistance heaters	Extra piping	10% to 25%	Neg.		X	X
- vacuum insulated panels (VIP)		Y	N	All types	Reduces thermal cond.	VIP	15%[2]	$400/m^2	X	X	X
Heat pipes		Y	N	All types	In cabinet shelves, improving product temperature	Integrated heat pipes	12%	n/k	X	X	X
Leak minimization											
- improved leak tightness	Y	Y	Y	All types	Degrees of improvement	Manufacturing kit	20%	10%	X	X	X
- leak detection	Y	Y	L	All types	Previously on large system	Sensors	15%	10%	X	X	X
Liquid pressure amplification	X	Y	N	Larger systems		Liquid pump	25%	30% of compressor cost	X	X	X
Liquid-suction HX (LSHX)	X	Y	Y	All types	Brazing pipes together	LSHX	0%	Various	X	X	X
Pipe insulation		Y	Y	All types	Normal practice	Pipe insulation	3%	n/k		X	X
Higher efficiency refrigerant	X	Y	Y	All types	See RTOC 2014, 2018	Refrigerant	RTOC 2014, 2018	+/-	X	X	(X)
Nanoparticles in refrigerant	X	Y	N	All types	Experimental, concerns	nanoparticles	20%	$20 – 100	X	X	X

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[2] Clodic and Zoughaib (2000).

Annex IV

AVAILABILITY OF COMPONENTS FOR AIR-CONDITIONING EQUIPMENT WITH LOW- AND MEDIUM-GLOBAL-WARMING POTENTIAL REFRIGERANTS

This annex presents information on availability and EE aspects relating to AC equipment.

Availability of compressors for AC equipment

1. The most common form of AC equipment, mini-split ductless systems, mainly use rotary type compressors. The simplest form of rotary compressor is “fixed-speed,” meaning it only has two modes: “on” or “off”. It turns on to cool a room and turns off once the room has reached the desired set temperature. “Variable-speed” compressors are inverter-driven and can operate at more than one speed to more efficiently and comfortably deliver the amount of cooling needed and maintain the desired temperature. The variable-speed units require electronic control systems, which can add to manufacturing costs.

2. Nearly all rotary compressor production is currently located in Asia and concentrated in China, as shown in Figure 5. Compressor manufacturing outside of China in descending order of capacity as of 2018 include Thailand, South Korea, Malaysia, Japan, India, Brazil, and the Czech Republic.

Figure 5. Global RAC Rotary Compressor capacity as at September 2018 (Nicholson et al 2019)

3. China is by far the world’s largest producer of compressors for room air-conditioner, with an estimated annual capacity of nearly 200 million units per year. In 2018, the four largest compressor manufacturers in China together accounted for over 60 per cent of global rotary compressor production capacity.

4. An analysis of company catalogues and websites found that rotary compressors using higher-GWP HCFC-22 and R-410A refrigerants accounted for the majority of models available worldwide in 2018, although many companies, mostly in Asia, now offer both fixed-speed and variable-speed compressors which use medium- and low-GWP HFC-32 and HC-290 refrigerants. However, the analysis found that none of the variable-speed compressor models identified use HCFC-22. In China, 42 per cent of the 167 million rotary compressors produced in 2017 were of the variable-speed type, compared to five years earlier in 2012, when these were only 30 per cent of 103 million.

5. Approximately 30 per cent of the rotary compressors produced in China in 2017 were designed to operate with the HCFC-22 refrigerant. While the quantity of HCFC-22 units has remained approximately constant over the past several years (Figure 6), the percentage of HCFC-22 units has declined in recent years, as the production of units using R-410A has increased to become the dominant type in China-produced rotary compressors.

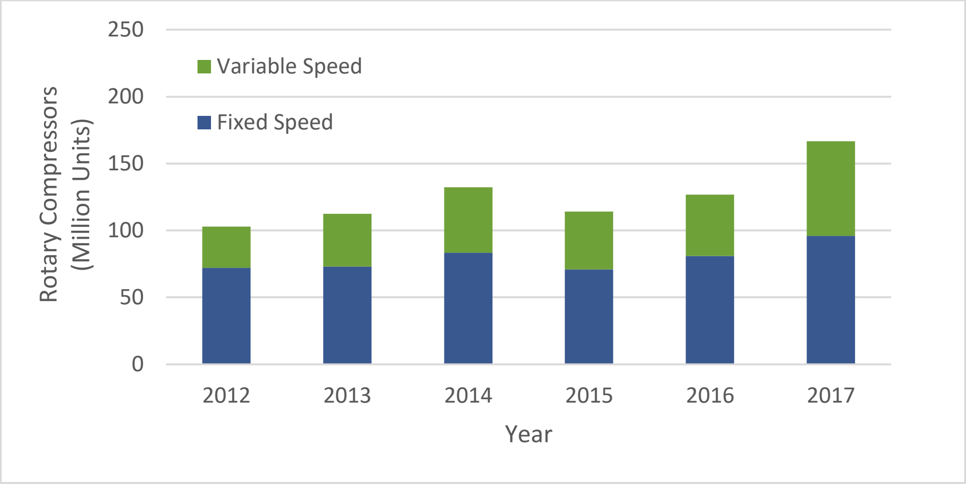
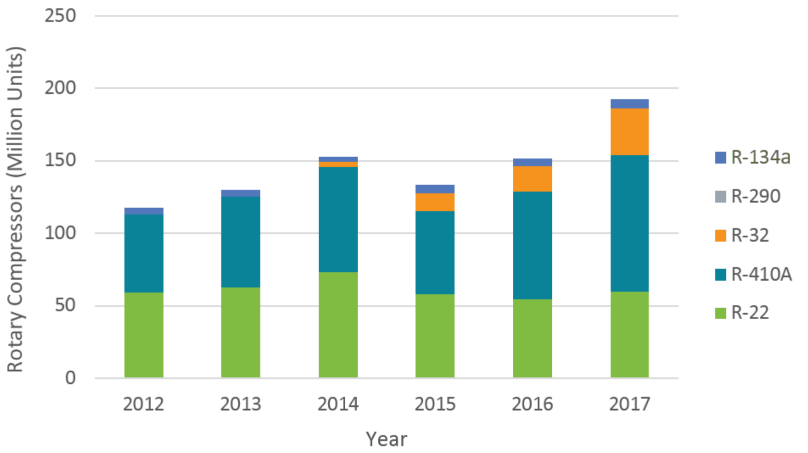


Figure 6. Chinese production of Fixed and Variable Speed Rotary Compressors, 2012-2017

6. Compressors for medium- and lower-GWP refrigerants (HFC-32 and HC-290) are mainly made in China.



Source: ChinaIOL

Figure 7. Chinese Production of Rotary Compressors by Refrigerant, 2012-2017

Note: HFC-134a rotary compressors are primarily used in mobile cooling applications, in contrast to the rest of the rotary compressor market which is used mainly for room (stationary) AC

7. As can be seen from the chart, the production of HC-290 compressors is not significant compared to the other refrigerants.

8. Some Middle East countries, especially with HAT conditions, continue to use reciprocating and scroll compressors in some of their production. Only a few rotary compressors are used for split AC units. Compressors operating at HAT conditions have specific design requirements (e.g. higher starting torque against the higher standing pressure during the off cycle; a motor-design suitable for those conditions). The technology for 2-ton units running on A2L refrigerants is available; however, commercial availability of compressors will depend on the demand.

9. The transition from fixed-speed to inverter compressors has sharply increased in the last five years to meet MEPS requirements, even though MEPS in some countries still list the full load efficiency figures only, rather than the seasonal efficiency figures. This is the case for Saudi Arabia where most of the AC units are fixed speed.

10. New compressor lubricants are being developed to be compatible with low-GWP synthetic refrigerants. Certain conventional polyester (POE) and polyvinyl ether (PVE) oils used for HFC refrigerants were insufficiently miscible with some refrigerants like HFC-32. New oils with better miscibility properties have been developed and patented for room AC use.

Availability of heat exchangers for AC

11. In most cases, the heat exchangers continue to be of the “fin-and-tube” type made from copper or aluminium. However, many companies are switching to use smaller tube diameter and micro-channel heat exchangers, which are already used in existing high-GWP AC split units. The most commonly used heat exchanger tube diameter for standard high GWP refrigerant are 3/8-inch (9.525 mm), ¼ inch (6.35 mm), and 7mm (~1/4 inch) tube diameter, but for the new refrigerants, some companies are using tubes of 5 mm diameter. These higher energy efficiency components reduce the refrigerant charge and are valuable in enabling medium and lower GWP refrigerant AC units to comply with safety standards. They are widely available. More information on heat exchangers in section 3.2.3 of TEAP Task Force report 2019.

Availability of fans for AC

12. Each split unit contains two fans (one in the outdoor unit and one in the indoor unit). Fan technologies are widely available. There are no special requirements for using efficient fans for medium and lower-GWP refrigerants.

Availability of refrigeration accessories for AC

13. The accessories for the refrigeration circuit used in the split AC units include the expansion device, liquid and gas valves, suction accumulator, liquid receiver, oil separator (if needed), and all accessories installed in the connecting pipes between all major components of the AC unit either in the gas side or liquid side of the unit. All of these components and accessories are available for high-GWP refrigerant applications and can be used for the medium- and low-GWP applications.

Annex V

AVAILABILITY OF COMPONENTS FOR AIR-CONDITIONERS AND SELF-CONTAINED COMMERCIAL REFRIGERATION EQUIPMENT LOW- AND MEDIUM-GLOBAL-WARMING POTENTIAL REFRIGERANTS

This annex presents information on availability and energy efficiency aspects relating to SCCRE.

Availability of compressors

1. A variety of different compressors are used in SCCRE, depending upon temperature lift, capacity, refrigerant type, and so on. For most types of compressors, efficiency improvements arise from marginal incremental refinements (such as oil distribution, valve losses, motor efficiency, internal leakage, flow path pressure losses, internal heat transfer, etc.). One major technological progression involves use and deployment of variable speed compressors, typically using inverter technology to enable the control of rotational speed over a fairly wide range. Variable speed compressors allow the mass flow of refrigerant to be adjusted to suit the cooling (or heating) demand so that the system components are essentially closer to the optimal balance point for the surrounding temperatures. Implicit in this is the lower mass flow (at sub-maximum load) which leads to reduced pressure losses and less frosting.

2. Usual compressors are hermetic reciprocating, scrolls and rotary (both vertical small print and horizontal when height restrictions apply). The remaining compressor developments have arisen from the increased use of R744, where much higher pressures, pressure ratios and pressure differences are present, compared to usual refrigerants. Although many of these developments are in principle beneficial to other refrigerants, they result in a costly approach for minor efficiency improvements.

3. The applicability to a specific climate/region depends more on daily or annual variation in temperature, rather than absolute high or low temperature.

Improved cabinet air flow

4. Improved cabinet air flow has a potentially huge impact on energy use and also product quality. Various physical approaches are available such as changes to configuration of air ducting and small plastic baffles and plates. Most are broadly cost-neutral but just require extensive R&D.

Energy-efficient fan/motors

5. Major transformation has occurred in the shape of electronic commutation (EC) motors, which offer significant reduction in energy use. Further benefits arise from design of fan structure and blade shape.

Doors on cabinets

6. Intuitively the use of doors on display cabinets should yield major energy benefits by retaining cold air and preventing spillage and entrainment of warm humid air. Major improvements are associated with “vertical” type cabinets, where infiltration ordinarily contributes to about 70 – 80 per cent of the heat load. The benefits are less with gondola (also known as well or coffin) type cabinets where infiltration is responsible for about 20 per cent of the load. Gaskets around glass doors also amplifies the benefit of using door.

Cabinet lighting

7. Historically SCCRE used fluorescent lamps but presently LEDs are almost ubiquitous. LEDs use less power and also reduce heat output (thus reducing heat load).

Defrost techniques

8. Historically a variety of defrost techniques have been used, including reverse cycle, hot gas, cool gas as well as electrical resistance heaters on "off-cycle" where air is continued to be passed over the frosted coil but with absence of refrigeration. Whilst reverse cycle, hot gas and cool gas defrost offer more efficient defrosting, they tend to be more costly to implement and have other implications that affect system reliability, such as causing thermal shock and thus increasing leakage. The most beneficial development related to defrost is control methodology so that defrosting-on-demand can be applied.

Controls

9. In addition to improved cabinet airflow, and in parallel with variable speed compressor drives, the most significant contribution to SCCR equipment (SCCRE) efficiency improvement has come from modern control technology. Application of the electronic expansion valve (EEV) and associated control software can yield substantial improvements in EE, although at present there is only limited application in SCCRE due to the relatively high cost, compared to other technologies. Control systems linking compressor modulation, EEVs, defrost-on-demand, lighting, trim-heaters, fan airflow rates as well as leak detection based on system parameters can have a major influence on energy consumption and optimisation of cycle efficiency. Adjusting the cooling to the use pattern e.g. while keeping the product at, say, 3°C if the shop is closed (such as during weekends, etc.). The set-point temperature can be adjusted to achieve the optimum balance between run time and pull-down energy demand. Such techniques are not applicable to perishable products.

Heat exchanger design

10. Features related to heat exchanger design are diverse and given the variation on SCCRE design, construction and function, it is difficult to make general statements on how much EE improvement particular approaches can offer and what the potential improvements could be. Target heat exchanger approach temperature difference should be below 5 K, for both evaporator and condenser. Often it depends upon the skill and knowledge of heat exchanger designers and manufacturers. In general, it is common practice today to use microchannel heat exchangers (MCHX) for condensers and brazed plate heat exchangers (BPHX) for liquid-cooled condensers, which simultaneously offer advantages in terms of charge reduction (preferred for flammable refrigerants). For smaller capacity units, wire-on-tube (WoT) condensers are used, which are low cost and provide sufficient levels of EE. The major advantage is however, that degradation due to dust accumulation over time is substantially.

Heat load

11. Lowering the heat load into the SCCRE helps reduce energy consumption per m^2 or per m^3 of refrigerated space, although it does not necessarily impact on the refrigeration cycle efficiency. Most approaches are based around limiting thermal transfer from electrical components, minimising radiant heat transfer from the surroundings and reducing conduction into the space.

Leak minimisation

12. Whilst leak minimisation is a priority for the application of flammable refrigerants, actions to retain the entire charge can significantly contribute to maintaining the "design" efficiency of a SCCRE. A deficit of refrigerant charge can go unnoticed until a certain level is reached, but in the meantime the compressor operates longer, and cycle efficiency degrades.

13. Whilst many of these technologies can in isolation produce substantive improvements in EE, combining two or more technologies will not result in summation of both improvements. Considered selection and iteration of implementation is necessary to obtain the most cost-effective benefit.

14. Many of the “older” technologies are now becoming redundant since newer technologies help bypass the need for others. For example, locating fan motors outside the cabinet is no longer worth the effort, when new EC fan motors only emit a fraction of heat of previous fan types

15. National or regional MEPS are the main driver for improving EE. Historically “in-situ” direct testing of energy use was riddled with misinterpretation and misunderstanding of measurements and results. Increasingly more rigorous methods are being developed. However, one of the main challenges is conducting tests that mimic real life conditions, which can vary widely and drastically affect comparative results.

16. Regulators in certain regions have introduced MEPS. However, the process has been turbulent in many cases due to the basis (dominator) for determining energy consumption, i.e., per internal volume, per display area, etc.

Annex VI

ADDITIONAL COSTS RELATING TO PRODUCTION LINE AND COMPONENT CHANGES FOR PRODUCING DOMESTIC AIR-CONDITIONERS USING FLAMMABLE REFRIGERANTS AND COST AND PERFORMANCE ANALYSIS OF ENERGY EFFICIENT REFRIGERATION AND AIR-CONDITIONING EQUIPMENT

1. Production line changes and additional requirements (modifications) to produce domestic AC units with flammable refrigerants will require production line equipment modifications and or replacements on each line including:

(a) Refrigerant recovery and charging machines for both A2L and A3 refrigerants (US $25,000 –US $50,000)

(b) Pressure testing equipment for high pressure refrigerant A2L (HFC-32) (US $15,000 – US $30,000)

(c) Refrigerant storage tank and accessories (3000 to 10000 litre) US $15,000 – US $40,000)

(d) Structural and safety modifications in the refrigerant charging area (including electrical panels, piping, anti-static floors and accessories) (US $15,000 – US $25,000)

(e) Modifications to the finished product testing areas (US $10,000 – US $20,000)

(f) Modifications for heat exchanger production line for tooling for smaller tube diameter, or establishment of new production lines for micro-channel heat exchanger (US $1,000,000 – US $1,500,000). It should be noted that smaller diameter or microchannel heat exchanger, the material cost is significantly reduced.

(g) Labour costs differ between countries, but extra costs will come in two main categories:

(i) Staff training to build capacity in dealing with flammable refrigerants and their safety requirements.

(ii) Additional staff cost to use more skilled workers.

2. The estimated cost for these items varies between countries and depends on the source of the equipment and availability of parts. For example, the cost of a refrigerant charging machine from China is 30 per cent lower than buying the same specification machine from Europe (in the range US $25,000 – US $50,000). There is additional cost in the finished product testing area for flammable refrigerant compared to non-flammable refrigerants, due to the additional piping, isolation valves and gas leakage sensors (5 to 10 sensors at ~ US $500 each) that are required in many locations.

Safety measures

3. Additional ventilation and fire-fighting equipment is required in the charging area, for safe manufacture any units for either A2L or A3 refrigerants with estimated costs as follows:

- Charging area ventilation system (US $10,000 – US $20,000)
- Charging area firefighting system including sprinklers and water storage tanks (US $20,000 – US $30,000)

Testing

4. Testing facilities are required at two locations, the production line and the laboratory for testing A2L and/or A3 refrigerants with the following estimated costs:

- The production line testing area (US $50,000 – US $75,000)
- The laboratory for product development (US $50,000 – US $75,000)

IP/technology know-how

5. The costs of technology transfer including IP and know-how are estimated as follows:

- Software (either developed in-house or outsourced from another specialized company: (US $0 – US $50,000)
- Building prototype(s) to verify performance and validate the software: (US $10,000 – US $20,000)
- IP cost is unknown but may be a royalty (in licensing) or a one-off license payment. For many A2L refrigerants there is substantial IP in terms of design of the refrigerant supply but moreover for system design, etc. With A3 refrigerants there is only very limited IP, and this is generally associated with "gadgets" and are thus not critical to their application.

Logistics

<u>Shipping</u>

6. This will include the additional shipping cost due to flammability for all material and/or components required for the manufacturing of the AC and CR equipment, and the additional cost of shipping finished goods either internally or abroad. This differs between countries. As an example, the shipping cost of a 40 ft container of flammable refrigerant from China to Jordan is US $1,900 compared to US $1,500 for non-flammable refrigerant. Some countries customs and clearance processes cost an additional 3-5 per cent.

<u>Handling</u>

7. This includes the cost of handling and storage of the flammable refrigerant and or finished product inside the manufacturing facilities and preparing it for inland, sea and air freight shipments. The handling process inside the factory requires the following precautions which increase the cost including:

- Storage of flammable refrigerant can be either inside a storage tank or smaller refrigerant cylinders, but both need adequate ventilation, and leakage monitoring systems: (US $20,000 – US $30,000)
- Handling the refrigerant and finished products inside the factory requires additional safety measures for transportation between the production departments and storage areas: (US $10,000 – US $15,000)
- Additional factory insurance and product liability insurance for flammable refrigerants: (US $8,000 – US $20,000)

Installation

8. This will include the additional costs of the training and awareness programs under the local jurisdiction; the extra cost of the certification and approvals from the jurisdiction party(s) to comply with the local building codes; international certification requirements to meet safety standards required in many countries for in the domestic A/C and commercial refrigeration equipment using flammable refrigerants.

9. This can be in different categories with the following estimates for costs:

(a) Training and awareness programmes with certification of workers, workshops etc. (US $10,000 – US $20,000)

(b) The certification cost for the new products (depending on the number of models needing to be certified, and the test standards requirements IEC, ISO, etc. (US $10,000 – US $15,000)

Overall costs summary

10. In summary, the overall costs, excluding shipping costs, are shown in Table 1 below. From this one can conclude the following at an overall level.

(a) The investment required to convert an RAC manufacturing facility to flammable refrigerants is in the range of 300,000 – 500,000 USD.

(b) The additional investment required to maximise energy efficiency by the establishment of new production lines for micro-channel heat exchangers is in the range 1,000,000 – 1,500,000 USD

Table 1: Estimates of the manufacturing costs for energy efficient RAC equipment containing low- and medium-GWP flammable refrigerants.

Conversion measure (USD)	**Minimum**	**Maximum**
Manufacturing		
Production line		
Refrigerant recovery and charging machines for both A2L and A3 refrigerants	25,000	50,000
Pressure testing equipment for high pressure refrigerant A2L (HFC-32) Refrigerant storage tank and accessories (3000 to 10000 Litre)	15,000 15,000	30,000 40,000
Structural and safety modifications in the refrigerant charging area (including electrical panels, piping, anti-static floors and accessories)	15,000	25,000
Modifications to the finished product testing areas	10,000	20,000
Modifications for heat exchanger production line for tooling for smaller tube diameter, or establishment of new production lines for micro-channel heat exchanger	1,000,000	1,500,000
Safety measures		
Charging area ventilation system	10,000	20,000
Charging area firefighting system including sprinklers and water storage tanks	20,000	30,000
Testing		
Production line testing area	50,000	75,000
Laboratory for product development	50,000	75,000
IP/technology know-how		
Software	0	50,000
Building prototype(s) to verify performance and validate the software	10,000	20,000
IP costs[1]	variable	variable
Logistics		
Shipping		
Additional costs	3%	5%

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[1] Please refer to section 3.1.1 discussion on IP related costs

Conversion measure (USD)	**Minimum**	**Maximum**
Handling		
Storage of flammable refrigerant can be either inside a storage tank or smaller refrigerant cylinders, but both need adequate ventilation, and leakage monitoring systems	20,000	30,000
Handling the refrigerant and finished products inside the factory requires additional safety measures for transportation between the production departments and storage areas	10,000	15,000
Additional factory insurance and product liability insurance for flammable refrigerants	8,000	20,000
Installation		
Training and awareness programmes with certification of workers, workshops	10,000	20,000
Certification cost for the new products (depending on the number of models needing to be certified, and the test standards requirements IEC, ISO)	10,000	15,000
Total without micro-channel heat exchanger production line or shipping)	**303,000**	**535,000**
Total with micro-channel heat exchanger production line (excluding shipping) (USD)	**1,300,000**	**2,035,000**

<u>AC: Cost of components</u>

11. The relative costs of energy efficient components are compared for a 3.5 kW mini-split in China. The baseline uses R-410A (APF 4.0) and HCFC-22 (EER 3.5) appliances. Certain components discussed in the following sub-chapter also apply to commercial refrigeration. These components will not be discussed in the chapter 3.3.

Refrigerant

12. Conventional refrigerants account for about 1 per cent of the total AC cost. The price of refrigerant always decreases with increasing consumption. Indicative prices of refrigerants commonly used in AC in China are shown in Fig 1. It is worth noting that in UK, the bulk HC (HC-290, HC-600a, HC-1270) price varies between USD 1 to USD 1.5 per kg. Furthermore, the average HCFC-22 price is USD 6/kg.

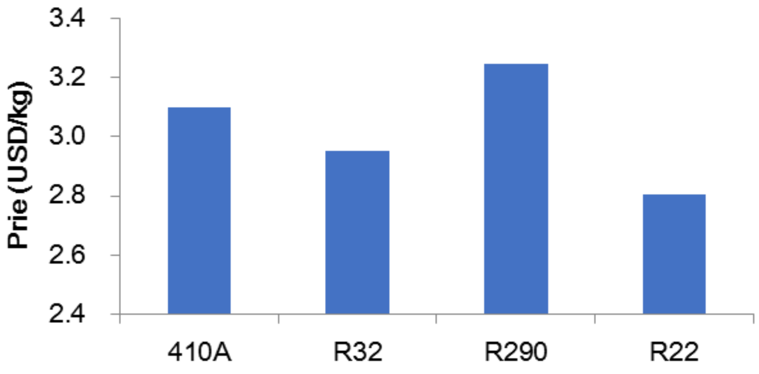

Figure 1. Estimates of refrigerant prices in China

13. The general price range of refrigerants is low, around 3 USD/kg +/-10 per cent. At an early stage, new refrigerants are more expensive, and difficult to get a foothold in the market. For example, R-290 is a by-product of the liquified natural gas (LNG) industry. Its production process is simpler than HFC-32, but its current price is slightly higher than HFC-32. However, when buying in bulk quantities, refrigerant-grade propane can be as low as US $1 per kg.

14. The cost of high-GWP HFCs will rise with the implementation of the F-gas regulation and Kigali amendment, both of which impact the competitiveness of products containing HFCs. For example, the quoted price of R-410A in Europe went up tenfold over 2017, and in 2018 is ~ 20 Euro/kg, which far exceeds the material cost of the refrigerant itself. This increases the competitiveness of medium- and low-GWP alternative refrigerants and greatly promote the commercialisation of environmentally friendly refrigerant technologies.

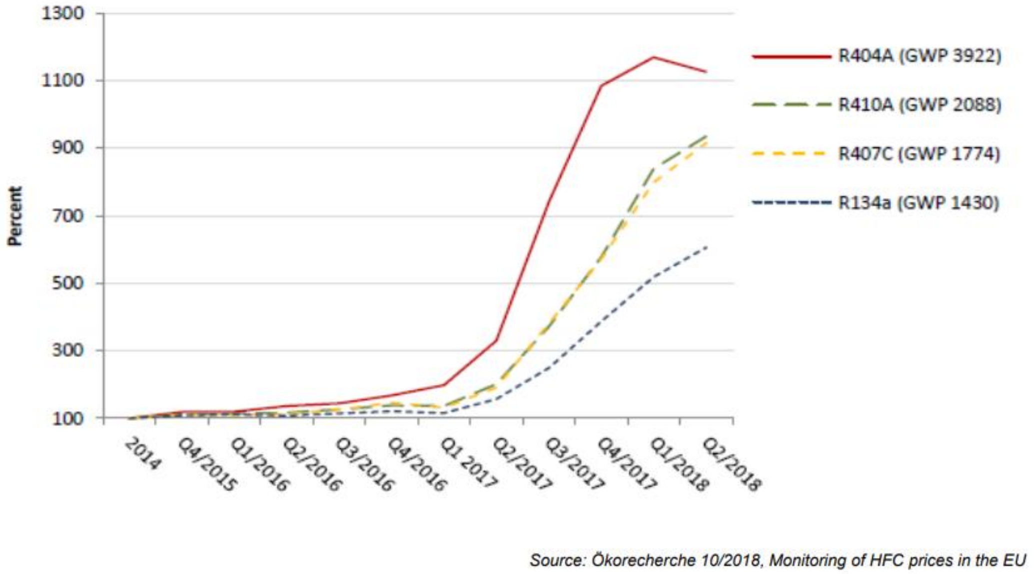

Figure 2. HFCs quota price trend in Europe (Ökorecherche, 2018)

Compressor

15. The compressor accounts for about 20 per cent of the total cost of AC systems. Improving compressor efficiency represents one of the most direct and effective measure to improve an air-conditioner's efficiency. Rotary compressors are the most commonly used. Piston compressors are used in some window air-conditioner especially in the Middle East, whilst scroll compressors are often used in lighter commercial products. Today, modern compressors have an efficiency of about 70 per cent. The majority of the losses are electrical and mechanical, with the remainder due to internal refrigerant leakage.

16. The most effective way to improve the efficiency of a compressor is to use a higher efficiency motor, but lower scale improvements can also be obtained using refrigerants with properties that provide higher thermodynamic efficiency, reducing inner leakage and mechanical friction. These will increase the cost of materials and manufacturing costs. Efficiency can be improved by up to 20 per cent by technical advances, but cost increases proportionately.

Heat exchangers

17. Finned tubes are the most commonly used heat exchangers for AC. The heat exchanger efficiency is mainly determined by the heat transfer coefficient, area and the flow friction and has a major impact on the system's cooling/heating capacity. The smaller the heat transferring temperature difference (i.e. the larger heat transferring coefficient multiplied by the area) and the smaller the flow friction, the higher the heat exchanger efficiency, which can be achieved. Measures to improve efficiency include heat transferring enhanced copper tubes and fins, increasing air volume, reducing contact thermal resistance between fins and copper tubes, improving manufacturing processing to reduce the damage to the heat transfer enhancing structure, and increase of the surface area and to improve the contact between tubes and fins. Most of these increase the cost of manufacturing. Recent considerations such as reducing the heat exchanger volume to

reduce the volume of refrigerant and the use of thinner tubes (<5mm diameter) have not yet been assessed in terms of manufacturing costs

18. The relationship between the heat transfer efficiency of finned tubes to the system energy efficiency, and accordingly increased cost are shown in the figure below. Both found a proportionate increase in heat transfer efficiency in relation to cost.

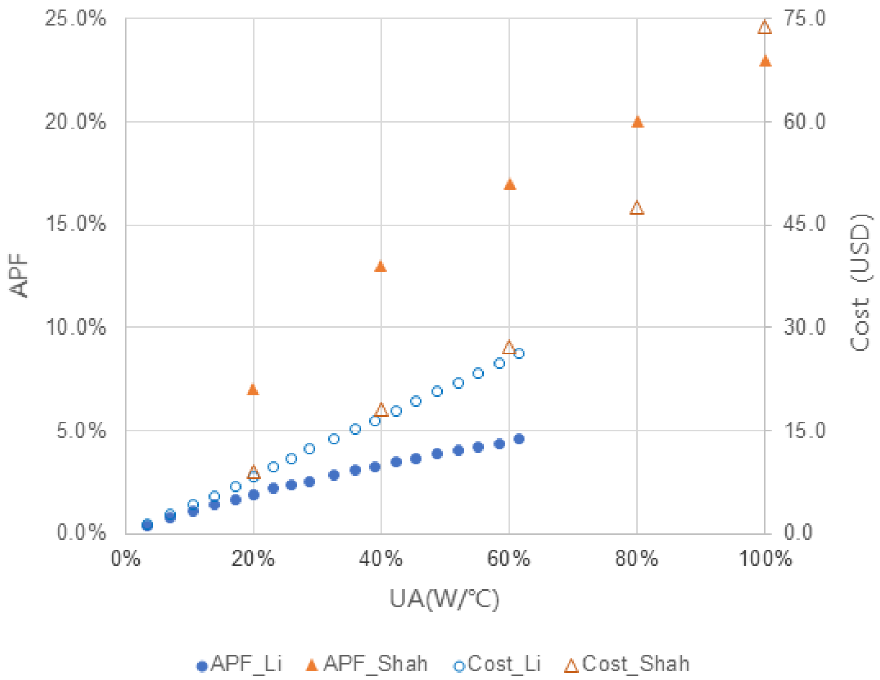

Figure 3. Heat exchanger cost and air-conditioner efficiency changing with heat exchanger efficiency

19. Micro-channel heat exchangers have a different mechanical structure, and approximately 40 per cent higher heat transfer efficiency than finned tube exchangers, due to:

- Higher air side heat transferring efficiency (larger tube area facing the airflow, with tubes connected with the fins by welding or by metal forming[2], rather than by expansion);
- Less refrigerant flow resistance due to shorter and more direct tubes;
- Higher refrigerant heat transfer coefficient
- Reduced system refrigerant charge by as much as 40 per cent.

20. Micro-channel heat exchangers require more complex to develop and are difficult to use them as evaporators. In addition, they can have higher maintenance costs because they are made from aluminium and the weld points can corrode in some conditions. Nevertheless, compared to finned tube heat exchangers, micro-channel heat exchangers have similar or marginally lower (~5 per cent) cost for the same capacity, and have higher (0-5 per cent) efficiency.

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[2] Metal forming, is the metalworking process of fashioning metal parts and objects through mechanical deformation; the workpiece is reshaped without adding or removing material, and its mass remains unchanged

Fans/motors

21. There are two main types of fan motor used in air-conditioners - direct current (DC, efficiency 70 per cent) and alternating current (AC, efficiency 30 per cent). DC motors have a much higher efficiency but are almost double the cost compared to AC motors.

22. AC efficiency can be improved by increasing airflow rate. The air volume flow is proportional to the power of the fan. There is an optimum airflow rate at which the air-conditioner has highest efficiency. If the airflow is less than the optimum, increasing airflow benefits the system efficiency. However, if airflow rate is greater than the optimum then system efficiency declines due to additional power needed to overcome high-pressure loss that has a diminishing benefit to heat transfer. The cost of the fan and motor increases with increasing airflow rates in a stepwise fashion, because a single fan/motor can cover a range of airflow rates. Selecting the correct fan for cost versus efficiency varies from case to case. As can be seen, there is an optimal fan speed, above which efficiency declines and cost increases.

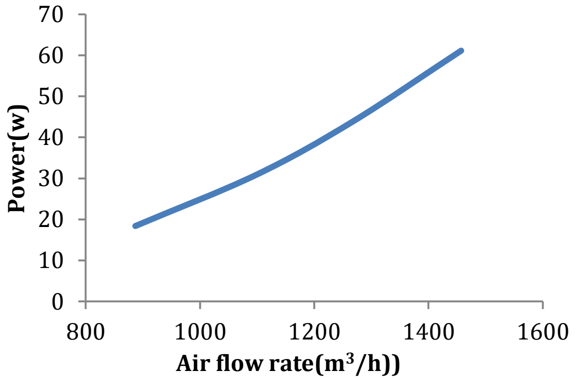

Figure 4. Schematic of fan power changing with airflow rate

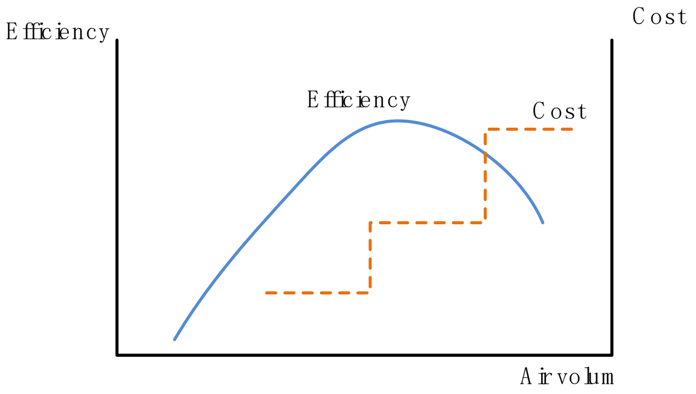

Figure 5. Schematic of air-conditioner efficiency and motor cost changing with air flow

Maintenance; self-cleaning

23. Most air-conditioners will have 5-10 per cent decline in efficiency during their lifetime, mainly due to dust deposition on heat exchange surface, the more complicated the fin geometry and the more rows of tubes, then the greater the dust deposition. As a result, the resistance to airflow increases and the air flow volume decreases, which reduces the efficiency of the heat exchanger and of the air-conditioner. Therefore, regular maintenance and cleaning of the AC system is essential in maintaining energy efficiency.

Increasingly, new products have a self-cleaning design at an additional cost of about $20 (Task Force estimate).

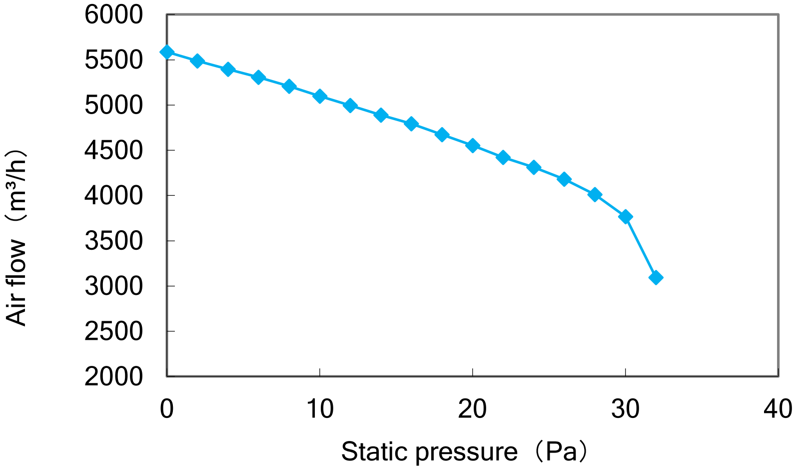

Figure 6. Schematic of airflow decrease changing with static pressure increase, to mimic dust build-up

Retrofit technologies

24. Several retrofit technologies offer EE improvements compared to baseline technologies. Some of these retrofit technologies include for room AC:

- Electronic, programmable, and self-learning Wi-Fi-enabled thermostat (estimated at 5 per cent energy saving);
- Central control system (estimated at 10 per cent energy saving); and
- Replacement of indoor and outdoor fan motors with variable speed ECM motors.

25. For commercial self-contained AC units, retrofit technologies include:

- Digital controllers to improve the compressor and fan controls;
- Adding doors/shields to vertical self-contained units;
- Replacing lighting with LED (reduce load and power draw); and
- Changing the thermostat set-point and reduce the glass-door heater power requirement
- Install anti-fog films on glass doors and deactivate glass door heaters (reduce load and power draw).

Costs of components for higher EE, specific to CR

26. As discussed in the previous sub-chapter, the energy consumption associated with a CR appliance is dictated not only by the system design and its components but also the construction of the equipment that is often unrelated to the system. Thus, there are a variety of elements that can be applied to commercial refrigeration appliances that may or may not be affected by the refrigerant type. Their cost can vary widely, depending upon the type of appliance, it’s size and also its function.

27. Table 2.7 in Chapter 2 of TEAP task force report lists all the often-considered options for improving SCCRE energy consumption; there are of course other options, but which may be applicable to non-self-contained or centralised type systems. The options have been broadly categorised according to its function, for example, improving airflow, improving fan energy, reducing heat load and so on. Of course, the effectiveness and cost of most of these options are interrelated. As noted above, the indicative additional

costs are applicable to certain classes of SCCRE, but also the size of the appliance; most of these apply to a 1.2 m or 2.5 m length cabinet.

System design and optimization

(ii) Cost-neutral EE upgrades

28. EE is one of the main design features that product development engineers consider during the development of new platforms, however, there are several other important factors that impact the design including manufacturability, reliability, cost, performance, etc. An engineer will always consider cost-neutral EE upgrades, whilst potentially improving other features. Some of the relevant examples of cost-neutral or cost-reduction EE upgrades include:

(a) Micro-channel heat exchangers;

(b) Improved fan designs;

(c) Optimized air flow distribution;

(d) Higher efficiency compressors; and

(e) Evaporator and Condenser design optimization (within certain limits)

(ii) Additional cost savings opportunities from EE measures

29. Some EE measures should be studied holistically, as they can increase or decrease costs elsewhere. For example, using brushless DC motors (electronically commutated motors, ECM) fans in commercial refrigeration units would require the use of more expensive electrical conductor (3- or 4-wires DC conductor instead of the usual 2-wires AC conductor). In contrast, a higher efficiency commercial refrigerator requires less electrical power and thus smaller electrical wire gauge and switches with a lower total installed cost.

30. All aluminium micro-channel heat exchangers reduce material cost, require lower refrigerant charge/cost, and because they are smaller and lighter result in reduced chassis cost, reduced cover cost, reduced packaging cost, and reduced transportation and storage costs.

(iii) System design and optimization case study: Sino - US CFC-Free Super-Efficient Refrigerator Project

31. During the phase-down of CFC refrigerants, parties were interested in providing energy efficient solutions. One of the major studies performed was the “The Sino - US CFC-Free Super-Efficient Refrigerator Project Progress Report: Prototype Design & Testing” to promote the transformation of the Chinese industry to the production of CFC-free, super-efficient domestic refrigerators. Technologies examined in that effort included:

(a) Non-CFC refrigerants and foam-blowing agents;

(b) Alternate refrigeration cycles;

(c) More efficient compressors;

(d) Optimization of condenser and evaporator designs;

(e) Increased insulation thickness; and

(f) Improvements to door gaskets and controls.

32. EPA (1997) reported that the China Household Electric Appliance Research Institute (CHEARI), the Haier Group, and the University of Maryland collaborated to build and test typical Chinese refrigerators, evaluate Chinese consumer opinion research on the marketing of ozone-friendly, energy-efficient refrigerators, and perform field testing for one year in three Chinese cities to test the performance of units under actual operating conditions. EPA (1997) concluded the following:

33. Laboratory tests have demonstrated that conversion from (CFCs) to alternative refrigerants and foam-blowing agents can be achieved along with substantial energy savings as shown Table 2.

Table 2: Summary of laboratory test results (EPA, 1997)

Energy savings	Technology improvement options employed
~20%	Lorenz cycle with non-CFC refrigerant blend
~20%	Increased foam insulation (about 2 cm) to sides, back, bottom, and (1 cm) to both doors of cabinet
~40%	Increased foam insulation and improved compressor
~50%	Increased insulation, improved compressor, and Lorenz cycle with non-CFC refrigerant blend

34. Chinese consumer opinion research showed that Chinese consumers care more about the quality of the product and they are willing to pay 20 per cent more for a higher quality product which consumes 40 per cent less energy than the models currently available.

35. The optimized models showed significant higher energy savings in the field than in laboratory tests; however, noise level was a concern with the field-tested units.