UNITED NATIONS

EP

United Nations Environment Programme

Distr.
GENERAL

UNEP/OzL.Pro/ExCom/84/49
29 November 2019

ORIGINAL: ENGLISH

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

PROJECT PROPOSALS: EGYPT

This document consists of the comments and recommendations of the Secretariat on the following project proposals:

<u>Phase-out</u>

• HCFC phase-out management plan (stage I, final progress report)	UNIDO and UNDP
• HCFC phase-out management plan (stage II, second tranche)	UNIDO, UNDP, UNEP, and the Government of Germany

Stage I of the HCFC phase-out management plan for Egypt (final progress report) (UNIDO and UNDP)

Background

1. On behalf of the Government of Egypt, UNIDO as the lead implementing agency, has submitted the following:

(a) The progress report on the implementation of the third tranche of stage I of the HCFC phase-out management plan (HPMP) for Egypt;

(b) Report on the status of conversion of the systems houses, the 81 small and medium-sized enterprises (SMEs) and the 350 micro users, and the report on the status of use of the interim technology (decision 82/72(b)(i) and (iv)); and

(c) The report on the project on the promotion of low-global warming potential (GWP) refrigerants for the air-conditioning industry in Egypt (EGYPRA).

Background on stage I of the HPMP

Manufacturing sector

2. All nine polyurethane (PU) foam manufacturing enterprises included in stage I[1], completed conversion with the total phase-out of 92.1 ODP tonnes of HCFC-141b. Stage I of the HPMP also included a project to convert 81 SMEs and 350 micro users to methyl formate (MF) or other low- GWP technology (to be selected during implementation), with the support from their systems houses and distributors, to phase out 75.74 ODP tonnes of HCFC-141b. Funding was approved for the equipment conversion at two Article 5-owned systems houses, and included technical assistance (TA) to all systems houses and distributors, and for the conversion of SMEs.

3. At the 82nd meeting, it was reported that one local systems house (Technocom) and one non-Article 5-owned (Dow) systems house converted. No funding from the Multilateral Fund for equipment conversion was provided to Dow; however, TA for the introduction of alternative foam blowing agents to downstream users was funded. One systems house withdrew from the project (Obeigi) and a memorandum of agreement (MOA)[2] with another (Baalbaki) was expected to be signed. A total of 24 downstream users had been assisted. The conversion of the remaining 57 downstream users was expected to be completed by the end of 2019.

4. Also at the 82nd meeting, it was reported that two systems houses (Dow and Technocom) were developing low-GWP formulations with water and hydrofluoro-olefins (HFO), but also with HFC-245fa, HFC-365mfc and HFC-227ea, substances controlled under the Kigali Amendment, notwithstanding that the use of high-GWP alternatives had been expected to be temporary, and their use phased out by 2015 at the latest. UNDP confirmed that no further assistance would be requested for the downstream users that had received assistance under stage I systems houses project as they agreed to convert to low-GWP technologies. UNDP also confirmed that incremental operating costs have not, nor will they be provided to customers unless a low-GWP technology is being used, in line with decision 77/35(a)(vi).

[1] Including six enterprises (funding for which was approved at the 62nd meeting) incorporated in stage I at the 65th meeting. The HCFC-141b phase-out project at Delta Electric Appliances, at a total cost of US $422,740, plus agency support costs was approved at the 62nd meeting; following the purchase of the enterprise by non-Article 5 entity the project had been cancelled and the approved funding was returned to the Fund at the 70th meeting.

[2] UNDP's project implementation arrangement.

5. At the 83rd meeting, it was reported that the MOA with Baalbaki to convert eight customers to phase out 53.7 mt of HCFC-141b had been signed. An addendum to the MOA with Technocom had been prepared to convert an additional 12 customers to phase out 11.37 ODP tonnes of HCFC-141b; that MOA was expected to be signed by May 2019. The alternative technologies for Baalbaki include water and MF, while for Technocom they include water-based and HFO systems; in both cases, HFCs are foreseen on an interim basis. At that time, no micro users had been converted; those conversions were expected to start in the second half of 2019.

6. Regarding the status on the use of technology, UNDP reported that water-based systems had been introduced by Dow and Technocom and approved by customers for certain applications; and further studies on the performance of HFOs in polyols were required as some systems houses reported problems in preparing systems, including their stability. UNDP continued to monitor the situation, and consultations with the national ozone unit (NOU) on barriers to the introduction of low-GWP technologies were planned for May 2019.

Enabling activities in the refrigeration and air-conditioning (RAC) sector

7. The EGYPRA initiative was launched in 2014 to assess low-GWP alternatives in the domestic and commercial air-conditioning (AC) sector by building and testing prototypes using various HCFC alternatives to compare the performance and efficiency of those alternatives, including at high ambient temperature. The project tested custom-built AC split unit prototypes, with capacities between 12,000 BTU/hr and 24,000 BTU/hr,[3] and central unit prototypes, with a cooling capacity of 120,000 BTU/hr,[4] to operate with alternative refrigerants and compared their performance against HCFC-22 and R-410A baseline units.

Report on HCFC consumption

8. The Government of Egypt reported a consumption of 287.45 ODP tonnes of HCFC in 2018, which is 26 per cent below the HCFC baseline for compliance. The 2014-2018 HCFC consumption is shown in Table 1.

Table 1. HCFC consumption in Egypt (2014-2018 Article 7 data)

HCFC	**2014**	**2015**	**2016**	**2017**	**2018**	**Baseline**
Metric tonnes						
HCFC-22	3,172.59	4,038.97	4,767.59	4,472.52	3,919.38	4,367.16
HCFC-123	0	9.07	5.00	1.64	2.00	5.25
HCFC-124	0.27	2.70	0.00	2.09	0.00	0
HCFC-141b	1,118.78	1,072.75	731.53	871.01	629.47	1,178.26
HCFC-142b	146.49	42.04	57.53	70.54	40.02	251.69
Total (mt)	**4,438.13**	**5,165.53**	**5,561.66**	**5,417.80**	**4,590.87**	**5,802.36**
HCFC-141b in imported pre-blended polyols	120.00	100.00	177.80	87.95	0	894.00*
ODP tonnes						
HCFC-22	174.49	222.14	262.22	245.99	215.57	240.19
HCFC-123	0	0.18	0.10	0.03	0.04	0.11
HCFC-124	0.01	0.06	0.00	0.05	0.00	0.00
HCFC-141b	123.07	118.00	80.47	95.81	69.24	129.61
HCFC-142b	9.52	2.73	3.74	4.59	2.60	16.36
Total (ODP tonnes)	**307.09**	**343.12**	**346.53**	**346.46**	**287.45**	**386.27**
HCFC-141b in imported pre-blended polyols	13.20	11.00	19.56	9.67	0	98.34*

*Average 2007-2009 consumption.

[3] BTU = British Thermal Unit. In tonnes of refrigeration (TR), 12,000 – 24,000 BTU/hr is 1-2 TR.
[4] 120,000 BTU/hr = 10 TR.

9. HCFC-22 is used in the manufacture and servicing of RAC equipment and to manufacture extruded polystyrene (XPS) foam. HCFC-22 consumption decreased in both the RAC manufacturing and servicing due to the reduced exports of HCFC-22-based AC units, and improved servicing practices. Given conversions in the PU foam manufacturing sector, HCFC-141b (pure) continues to decline while, in line with the 2018 ban, no HCFC-141b contained in imported pre-blended polyols was reported in 2018. HCFC-142b is used in the manufacture of XPS foam and is imported as a component of R-406A, a drop in blend for CFC-12-based equipment.

Country programme (CP) implementation report

10. The Government of Egypt reported HCFC sector consumption data under the 2018 CP implementation report which is consistent with the data reported under Article 7 of the Montreal Protocol.

<u>Progress report on the implementation of the third tranche of the HPMP</u>

Legal framework

11. The HCFCs licensing and quota system (except for HCFC-141b in imported pre-blended polyols) came into force in 2013. The Government has banned the import of HCFC-141b in pre-blended polyols as of 1 January 2018. The ban is implemented through the cooperation between the Egyptian Environmental Affairs Agency (EEAA) and Customs Authority whereby the customs authority checks all imports under the general Harmonized System code for polyols with the assistance of the NOU. In line with decision 79/34(c)(ii), the Government will ban the import, use and export of HCFC-141b in bulk and the export of HCFC-141b contained in pre-blended polyols effective 1 January 2020.

Manufacturing sector

12. The project to convert 81 SMEs to low-GWP technology is progressing, with an MOA signed with the three systems houses, Baalbaki, Dow, and Technocom to convert 64 downstream customers; an addendum to the MOA with Baalbaki for the conversion of an additional six customers is expected to be signed by 30 November 2019. Of the 64 downstream customers, 44 have been converted and have signed a commitment to stop the use of HCFC-based systems; a further three customers have been converted and are in the process of signing such a commitment, expected by the end of the 2019. The exact number of remaining downstream customers will be confirmed during implementation; the conversion of all downstream customers is expected to be completed by the end of 2019.

13. Most micro users purchase systems irregularly and through distributors rather than directly through the systems houses, making their identification challenging. An awareness workshop was held in September 2019 to identify all micro users to ensure that they will complete the conversion to non-HCFC alternatives by 1 January 2020. To date, no micro user has been converted with assistance from the project.

Report on the status of use of the interim technology

14. The three systems houses, Baalbaki, Dow, and Technocom, have successfully enabled the conversion of their downstream customers to low-GWP alternatives, including water, HFOs, and MF. The systems houses also produce high-GWP systems and sell those systems to downstream customers but not those assisted under the project.

15. One systems house had previously reported processing problems with an HFO. On an interim basis, the systems house had instead switched to a different HFO that resolved the issue; however, that HFO is more expensive and, given its new introduction in the region, there were concerns about uninterrupted

delivery. UNDP continues to monitor the situation and expects the systems house will be able to resolve the processing problems it encountered with the original HFO, as the other two systems have.

Enabling activities in the RAC sector

16. Nineteen custom-built split unit prototypes with dedicated compressors provided by a number of enterprises were tested at locally available accredited labs with refrigerants provided by Arkema, Chemours, Daikin, and Honeywell. Details of the test results are presented in Annex I of the present document. The results of EGYPRA informed the selection of low-GWP alternatives by the residential AC manufacturing sector enterprises.

Level of fund disbursement

17. As of October 2019, of the US $6,148,975[5] approved so far, US $4,265,938 had been disbursed (US $1,255,818 for UNIDO and US $3,010,120 for UNDP) as shown in Table 2. The balance of US $1,883,037 will be disbursed in 2019 and 2020.

Table 2. Financial report of stage I of the HPMP for Egypt (US $)

Tranche		**UNIDO**	**UNDP**	**Total**	**Disbursement rate (%)**
First tranche	Approved	950,000	2,000,000	2,950,000	98
	Disbursed	950,000	1,954,628	2,904,628	
Second tranche	Approved	250,000	2,000,000	2,250,000	58
	Disbursed	250,000	1,055,492	1,305,492	
Third tranche	Approved	232,575	716,400	948,975	6
	Disbursed	55,818	0	55,818	
Total	Approved	1,432,575	4,716,400	6,148,975	69
	Disbursed	1,255,818	3,010,120	4,265,938	

Secretariat's comments

Comments on the annual report on stage I of the HPMP

Legal framework

18. The Government of Egypt has issued HCFC import quotas for 2019 at 289.7 ODP tonnes, which is lower than the Montreal Protocol control targets, and in line with the targets specified in the Agreement between the country and the Executive Committee.

Report on the status of use of the interim technology

19. While the three systems houses have successfully enabled the conversion of their downstream customers to low-GWP alternatives, including water, HFOs, and MF, the systems houses also produce high-GWP systems and sell those systems to downstream customers other than those assisted under the project. In order to ensure the sustained use of low-GWP alternatives at the downstream customers after project completion, UNDP's handover protocol procedure will not allow the systems houses to use high-GWP alternatives at downstream customers that participated in the project.

[5] In addition, US $2,371,840 plus agency support costs was approved for six investment projects at the 62nd meeting and included in stage I (excluding funding for Delta Electric Appliances that subsequently withdrew from stage I).

Enabling activities in the RAC sector

20. The Secretariat noted with appreciation the comprehensive report of EGYRPA. While the testing for the split units has been completed, additional time is required to complete the testing for the central units, which have already been built, to draft the final report, which will be submitted to the 86th meeting, and to complete work on a modeling tool that can be used by local manufacturers. Accordingly, UNIDO requested to extend the date of completion for stage I of the HPMP to 30 June 2020, noting that all other components of stage I would be completed by 31 December 2019, that the project completion report would be submitted to the 87th meeting, and UNIDO would return all balances by 30 June 2020, while UNDP would return balances by 31 December 2020 (in line with the date of financial completion of the PU foam sector).

21. Given its relevance to the selection of low-GWP alternatives in the AC manufacturing sector, the Secretariat's summary of the EGYPRA report as well as the report itself are annexed to the present document. The findings of EGYPRA directly informed the technology selection for the project to convert five residential AC manufacturers to low-GWP alternatives submitted to the present meeting, in line with decision 79/34(d). The final report, once available, will be added to the Multilateral Fund's website.[6]

22. The Secretariat sought clarification on whether the findings and conclusions of EGYPRA were the same as other testing programmes that have similarly tested low-GWP alternatives in the AC manufacturing sector, including demonstration projects funded by the Multilateral Fund. EGYPRA was not compared against the final report on the demonstration project at AC manufacturers to develop window and packaged air conditioners using refrigerants with low GWP in Saudi Arabia nor with the final report on the demonstrative project for HCFC-22 phase-out in the manufacturing of commercial air-conditioning equipment at Industrias Thermotar Ltda in Colombia; however, it was compared against three testing programmes: AREP-II,[7] ORNL,[8] and PRAHA.[9] A description of EGYPRA's distinctive features and comparison against the three testing programmes are contained in Annex I to the present document.

<u>Conclusion</u>

23. The Government is enforcing a licensing and quota system for the import and export of HCFCs, and consumption in 2018 is below the control targets of the Montreal Protocol and those stipulated in the Agreement with the Executive Committee. The ban on the import of HCFC-141b in pre-blended polyols is in place since 1 January 2018, and the ban on the import, use and export of HCFC 141b in bulk and the export of HCFC-141b contained in pre-blended polyols will be established by 1 January 2020. The overall disbursement rate is 69 per cent. TA activities in the RAC sector are being successfully implemented with both domestic and commercial AC prototypes built, though some additional time is required to test the central AC units, which have already been built; accordingly, an extension until 30 June 2020 is needed. The three systems houses have successfully enabled the conversion of their downstream customers to low-GWP alternatives, and the foam sector will be completed by 31 December 2019.

[6] Factsheets and final reports for demonstration projects on low-GWP alternatives to HCFC technologies, http://multilateralfund.org/Our%20Work/DemonProject/default.aspx

[7] AHRI Alternative Refrigerant Evaluation Program http://www.ahrinet.org/arep

[8] Abdelaziz 2015 Abdelaziz O, Shrestha S, Munk J, Linkous R, Goetzler W, Guernsey M and Kassuga T, 2015. "Alternative Refrigerant Evaluation for High-Ambient-Temperature Environments: R-22 and R-410A Alternatives for Mini-Split Air Conditioners", ORNL/TM-2015/536. Available at: https://www.energy.gov/sites/prod/files/2015/10/f27/bto_pub59157_101515.pdf .

[9] PRAHA Project Report: https://www.unenvironment.org/resources/report/promoting-lowgwp-refrigerants-air-conditioning-sectors-high-ambient-temperature

Secretariat's recommendation

24. The Executive Committee may wish:

(a) To note the following submitted by UNIDO, contained in document UNEP/OzL.Pro/ExCom/84/49:

(i) Progress report on the implementation of the third tranche of the stage I of the HCFC phase-out management plan (HPMP) for Egypt;

(ii) Report on the project on the promotion of low-global warming refrigerants for the air-conditioning industry in Egypt (EGYPRA);

(iii) Report on the status of conversion of the systems houses, the 81 small and medium-sized enterprises and the 350 micro users and the report on the status of use of the interim technology;

(b) To note that all activities for stage I of the HPMP for Egypt will be completed by 31 December 2019, any remaining balances returned by 31 December 2020, except for UNIDO's component in the servicing sector which will be completed by 30 June 2020;

(c) To approve the extension of stage I of the HPMP to 30 June 2020 to allow the completion of activities in sub-paragraph (b);

(d) To request the Government of Egypt and UNIDO to submit the final report on EGYPRA to the 86th meeting; and

(e) To request the Government of Egypt and UNIDO to submit progress reports on a yearly basis on the implementation of the work programme associated with the final tranche of stage I through the completion of the project, and the project completion report to the 87th meeting.

PROJECT EVALUATION SHEET – MULTI-YEAR PROJECTS

Egypt

(I) PROJECT TITLE	AGENCY
HCFC phase-out plan (Stage II)	UNIDO (lead), UNDP, UNEP, Germany

(II) LATEST ARTICLE 7 DATA (Annex C Group l)	Year: 2018	287.45 (ODP tonnes)

(III) LATEST COUNTRY PROGRAMME SECTORAL DATA (ODP tonnes)									Year: 2018
Chemical	Aerosol	Foam	Fire fighting	Refrigeration		Solvent	Process agent	Lab use	Total sector consumption
				Manufacturing	Servicing				
HCFC-22		32.19		85.83	97.54				215.57
HCFC-123					0.04				0.04
HCFC-141b		69.24							69.24
HCFC-142b		2.60							2.60
HCFC-141b in imported pre-blended polyol		0							0

(IV) CONSUMPTION DATA (ODP tonnes)			
2009 - 2010 baseline:	386.3	Starting point for sustained aggregate reductions:	484.61
CONSUMPTION ELIGIBLE FOR FUNDING (ODP tonnes)			
Already approved:	174.00	Remaining:	310.61

(V) BUSINESS PLAN		2019	2020	2021	After 2021	Total
UNIDO	ODS phase-out (ODP tonnes)	10.13	0	12.54	12.75	35.42
	Funding (US $)	807,850	0	1,000,450	1,016,714	2,825,014
UNDP	ODS phase-out (ODP tonnes)	24.62	0	10.96	0	35.58
	Funding (US $)	1,965,323	0	873,783	0	2,839,106
UNEP	ODS phase-out (ODP tonnes)	3.75	0	3.49	3.83	11.07
	Funding (US $)	312,894	0	291,064	319,611	923,569
Germany	ODS phase-out (ODP tonnes)	2.78	0	0	0	2.78
	Funding (US $)	234,249	0	0	0	234,249

(VI) PROJECT DATA			2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Montreal Protocol consumption limits			347.64	347.64	347.64	251.08	251.08	251.08	251.08	251.08	125.54	n/a
Maximum allowable consumption (ODP tonnes)			347.64	289.70	289.70	251.08	251.08	251.08	251.08	251.08	125.54*	n/a
Agreed funding (US $)	UNIDO	Project costs	3,356,641	0	755,000	0	935,000	0	755,200	0	195,000	5,996,841
		Support costs	234,965	0	52,850	0	65,450	0	52,864	0	13,650	419,779
	UNDP	Project costs	1,042,352	0	1,836,750	0	816,620	0	0	0	0	3,695,722
		Support costs	72,965	0	128,573	0	57,163	0	0	0	0	258,701
	UNEP	Project costs	230,000	0	279,500	0	260,000	0	180,000	0	105,500	1,055,000
		Support costs	27,480	0	33,394	0	31,064	0	21,506	0	12,605	126,050
	Germany	Project costs	0	0	207,300	0	0	0	0	0	0	207,300
		Support costs	0	0	26,949	0	0	0	0	0	0	26,949
Funds approved by ExCom (US $)		Project costs	4,628,993	0	0							4,628,993
		Support costs	335,410	0	0							335,410
Total funds requested for approval at this meeting (US $)		Project costs			3,078,550							3,078,550
		Support costs			241,766							241,766

* Maximum allowable total consumption of Annex C, Group I substances would be further reduced by no more than 10 ODP tonnes upon approval of a domestic air-conditioning sector plan as part of stage II

Note: Revised agreement to be considered at the 84th meeting.

Secretariat's recommendation:	For individual consideration

PROJECT DESCRIPTION

25. On behalf of the Government of Egypt, UNIDO as the lead implementing agency, has submitted a request for funding for the second tranche of stage II of the HCFC phase-out management plan (HPMP), at a total cost of US $3,320,316, consisting of US $755,000, plus agency support costs of US $52,850 for UNIDO, US $1,836,750, plus agency support costs of US $128,573 for UNDP, US $279,500, plus agency support costs of US $33,394 for UNEP, and US $207,300, plus agency support costs of US $26,949 for the Government of Germany.[10] The submission includes a progress report on the implementation of the first tranche, the verification report on HCFC consumption for 2018 and the tranche implementation plan for 2019 to 2021.

26. At the 79th meeting, the Executive Committee decided to invite, on an exceptional basis, the Government of Egypt to submit, once a technology had been selected, and prior to 1 January 2020, a proposal, as part of stage II, to convert the domestic air-conditioning sector to alternatives with low global-warming potential (decision 79/34(d)). On behalf of the Government of Egypt, UNIDO, has submitted a project to convert the HCFC-22 residential air-conditioning in the manufacturing sector at the amount of US $11,710,018, plus agency support costs of US $819,701, as submitted. The project, should it be approved, would be subsumed into the Agreement for the stage II of the HPMP with the Executive Committee.[11]

Report on HCFC consumption

27. As described in paragraph 8 of the present document, the Government reported HCFC consumption of 287.45 ODP tonnes in 2018, which is below the target specified in the country's Agreement with the Executive Committee for 2018, and 26 per cent below the HCFC baseline for compliance.

Verification report

28. The verification report confirmed that the Government is implementing a licensing and quota system for HCFC imports and exports and that the total consumption of HCFCs for 2018 was 287.48 ODP tonnes. The verification concluded that Egypt has been in compliance with the 2018 maximum allowable consumption of all Annex C, Group I substances, as in its Agreement with the Executive Committee, and that the verified consumption and that reported under Article 7 of the Montreal Protocol are consistent within rounding accuracy. The report notes that suspicious shipments of controlled substances found at the port of entry are stopped by the Customs Authority, and the NOU and the General Organisation of Import and Export Control are informed. Upon confirmation that the shipment is not in conformity with the issued license, and the importer has had the chance to request further verification, the importer must return the shipment to the exporter at the importer's expense; moreover, the exporting country is notified through the informal Prior Informed Consent (iPIC) mechanism and needs to give approval for the re-importation of the shipment. This process was followed for two suspicious shipments of ODS in 2010; since that time, no suspicious shipments have been identified, including containing CFC-11 or CFC-12. Following an amendment to the law for hazardous waste in 2009, the penalty for the contravention of the country's import regulations for controlled substances may include imprisonment (up to five years) and a fine between 20,000 and 40,000 Egyptian Pounds (between approximately US $1,240 and US $2,842).

[10] As per the letter of 18 September 2019 from the Ministry of Environment of Egypt to UNIDO.
[11] As per the letter of 18 September 2019 from the Ministry of Environment of Egypt to UNIDO.

Progress report on the implementation of the first tranche of the HPMP

Activities in the manufacturing sector

Polyurethane (PU) foam manufacturing sector

29. The PU foam manufacturing sector included: the conversion of the remaining eight enterprises manufacturing domestic refrigerators to cyclopentane (Bahgat, Fresh, Ocean, Siltal, Star, Top Maker and Tredco, with assistance from the Multilateral Fund; the enterprise Everest would fund its conversion with its own resources); the conversion of two enterprises (Electrostar and Kiriazi) that manufacture electric water heaters to cyclopentane; and a group project through the systems house Beta Technical and Trading Bureau for the phase-out of 38 small- and medium-sized enterprises (SMEs) to methyl formate (MF), with funding from the Multilateral Fund for 28 SMEs and 10 SMEs converting with their own resources. The total phase-out of HCFC-141b for which funding was approved in the domestic refrigeration manufacturing sub-sector was 422.50 mt (46.48 ODP tonnes), and 49.79 mt (5.48 ODP tonnes) in the remaining PU insulating foam sub-sector, for a total of 472.29 mt (51.95 ODP tonnes). Everest and the additional 10 SMEs would phase-out an additional 114.43 mt (12.59 ODP tonnes) with their own resources. The Executive Committee noted that the Government of Egypt would have flexibility to allocate funding to eligible enterprises in the PU foam sector for which funding had been not requested, if that were deemed necessary during implementation (decision 79/34(e)).

30. The eight enterprises manufacturing domestic refrigerators were visited, a working arrangement[12] with each was signed, and terms of reference prepared. International bidding was completed for the seven enterprises for which funding from the Multilateral Fund was approved, equipment providers were selected, and purchase orders issued. Equipment has been delivered to three enterprises (Bahgat, Fresh, and Star) and installation and commissioning is ongoing; delivery of equipment for a further two enterprises (Siltal and Tredco) is expected by October, with installation and commissioning expected to be completed by 31 December 2019. Equipment for Ocean and Top Maker is expected to be delivered by 31 December 2019; installation and commissioning are expected to be completed in the first quarter of 2020. Both enterprises will cease manufacturing HCFC-based foam starting 1 January 2020. Equipment for Everest, the enterprise for which funding was not approved, is expected to be delivered by the end of 2019, with installation and commissioning expected to be completed in the first quarter of 2020. The enterprise has committed to cease manufacturing HCFC-based foam starting 1 January 2020.

31. Memoranda of Agreement (MOA)[13] with the two enterprises that manufacture electric water heaters (Electrostar and Kiriazi) have been signed. International bidding was completed, equipment providers were selected, and purchase orders issued. Equipment is expected to be delivered by 31 December 2019; installation and commissioning are expected to be completed in the first quarter of 2020. Both enterprises will cease manufacturing HCFC-based foam starting 1 January 2020.

32. The MOA with Beta Technical and Trading Bureau has been signed and trials with MF at 24 SMEs have been completed; those customers have signed a statement of completion and commitment to cease manufacturing HCFC-based foam. Trials at the four remaining SMEs for which funding was provided are ongoing; conversion to MF is expected to be finalized by 31 December 2019. UNDP confirmed that all 28 SMEs are eligible for funding. The remaining 10 SMEs were found to be not eligible for funding; while the status of their conversion, and the alternative(s) selected, is unknown, their conversion will be completed by 31 December 2019, in line with the 1 January 2020 ban.

[12] UNIDO's project implementation arrangement.
[13] UNDP's project implementation arrangement.

Technical assistance (TA) to the residential AC manufacturing sector

33. Based on data provided by five residential AC manufacturers (El-Araby, Fresh, Miraco, Power and Unionaire) on baseline units and the planned conversion, refrigerants change-over along with performance data for validation were assessed. The international consultant performed extensive modeling, validation, and performance optimization for the different manufacturers. Models have been developed for baseline equipment and validated. Simulations have been performed using the suggested alternative refrigerants as drop-in and as soft-optimized to match the baseline capacity. Site visits were organized during which training on the system simulation tool (ORNL Heat Pump Design Model) has been delivered, as well as a design workshop to further improve the system performance while changing the system refrigerant to lower GWP refrigerant.

Activities in the refrigeration servicing sector

34. The following activities were completed:

(a) Protocol signed between the Egyptian Environmental Affairs Agency (EEAA) and the Consumer Protection Agency (CPA), to monitor and curb counterfeit refrigerant products in local market; development of terms of reference for a study on the socioeconomic impacts of the HCFC phase-out and the use of alternatives in the RAC sector;

(b) Workshop to train-the-trainers for 30 CPA inspectors, and eight workshops to train 140 CPA inspectors in two governorates were organized, with a further 10 workshops to train 175 CPA inspectors in the remaining governorates planned for October 2019. Topics included legislation and monitoring of HCFC supply and use;

(c) Protocol signed with Ministry of Industry and Trade, to review the regulations and policies and introduce measures to tighten the oversight of controlled substances; customs codes for controlled substances updated according to the World Customs Organization updates;

(d) Purchase of 10 refrigerant identifiers for use by customs and CPA inspectors, and a training for 180 inspectors on their use;

(e) Ministerial decision issued on 25 July 2019 updating the list of controlled substances to includes all imported HCFCs blends; regulatory import publication by the Custom Authority in 2019 to ban the import of HCFC-141b from 1 January 2020; updating of import permits for HCFC-22 to limit imports to 40 mt;

(f) Activities to establish the refrigerant market surveillance programme have been initiated, including by amending the operating procedures of Egyptian Consumer Protection Law (181/2018) by including controlled substances in those procedures, and development of awareness-raising campaign materials targeting traders, retailers and consumers about fraudulent products; the campaign is expected to start in January 2020;

(g) Cooperation protocols signed with the two vocational training schools to build a national certification programme and a draft certification scheme is under final review; cooperation protocol signed with the Egyptian Organization for Standards and Quality (EOS), which started preparing guidelines to be implemented by the Ministry of Manpower for issuing certification to servicing centres and to technicians;[14] and a call for proposals for a pilot centre for refrigerant recovery and reclamation service has been published;

(h) Update to local technical education and vocational curricula drafted, assessment of equipment and tools needed for training; update and assessment under final review;

(i) Cooperation protocol signed with the Housing and Building Research Centre (HBRC) to update national codes and facilitate the introduction of low-GWP alternatives; and

(j) National awareness-raising campaign on low-GWP alternatives was designed, with three workshops for 188 participants and a technical seminar on low-GWP alternatives for approximately 50 researchers at the Institute of Environmental Studies and Research, Ain Shams University.

Project implementation and monitoring unit (PMU)

35. The project management was divided into two components, one relating to UNIDO and the other to UNDP, for managing the respective project activities, with the former overseeing all project activities and overall coordination. UNIDO recruited national consultants to coordinate and monitor project implementation, including visiting beneficiaries and stakeholders; organize workshops, meeting and events; and draft and circulate support documentation and awareness-raising materials (US $89,397). UNDP recruited a project manager to visit beneficiaries; provide technical support on equipment specification and report on implementation progress; develop contracts for beneficiaries, in consultation with the NOU and UNDP; daily implementation of HPMP activities; and financial control (US $14,314).

Level of fund disbursement

36. As of September 2019, of the US $4,628,993 approved so far (US $3,356,641 for UNIDO, US $1,042,352 for UNDP, and US $230,000 for UNEP), US $1,523,242 (33 per cent) had been disbursed (US $895,028 for UNIDO, US $465,314 for UNDP and US $162,900 for UNEP). The balance of US $3,105,751 will be disbursed in 2020-2021.

Implementation plan for the second tranche of the HPMP

37. The following activities will be implemented between January 2020 and December 2022:

(a) Continued policy development, enforcement and monitoring, and training, including on the refrigerant market surveillance programme; further development of technician certification scheme, update local technical education and vocational curricula, and launching of a pilot certification programme (UNEP) (US $140,000);

[14] There are three different certification schemes in Egypt, one led by the Ministry of Manpower, another under the vocational training programme, and the third is part of the technical education scheme led by Ministry of Education. Currently, minimum qualification certificates are required depending on the profession and employer; each of the three programmes qualify technicians as required by the market; however, servicing best practices do not form part of the requirements, nor do best practices related to the handling of flammable refrigerants.

(b) Continued collaboration with HBRC to update national codes, review of local standards for equipment and containers, and training and outreach on the codes and standards (UNEP) (US $79,500);

(c) Green procurement training for the public sector, advisory group and consultants (UNEP) (US $60,000);

(d) Purchase of approximately 15 refrigerant identifiers (US $60,000) and establish two master training centres (US $60,000) (UNIDO);

(e) Establishing a local reclamation centre, including a local independent testing lab (US $150,000) and build the recovery and reclamation network by supplying recovery units and cylinders (US $150,000) (UNIDO);

(f) Two stakeholder workshops for vocational training centre (VTC) on flammable refrigerants; selection of VTC and associated capacity assessment and gap analysis; four trainings for master trainers (including tools and equipment for A2, A2L and A3 refrigerants; brazing competences and tube pressing joining methods; refrigerant circuit manipulations; refrigerant recovery, venting and disposal; reporting, logbook, and assessment), and the purchase of equipment, tools, personal protection equipment and training units for the VTC (Government of Germany) (US $207,300);

(g) Continued development of a simplified free-to-use modeling software that can be used by residential AC manufacturers for product development (UNIDO) (US $100,000);

(h) Provide TA and build prototypes at three commercial AC manufacturers with low-GWP for applications with capacity less than 10 tonnes of refrigeration (TR), and combined indirect evaporative cooling and direct expansion (of low-GWP alternative) for applications with capacity in the 12-40 TR range (UNIDO) (US $110,000);

(i) Conversion of four extruded polystyrene (XPS) foam manufacturers to 60/40 blend of HFO-1234ze and dimethyl ether (UNDP) (US $1,761,750); and

(j) The PMU will continue coordinating and monitoring implementation of non-investment and investment activities, including visiting beneficiaries and stakeholders, and organizing workshops and meetings (UNIDO) (US $125,000); it will start-up the conversion of XPS foam enterprises, including regular visits to the beneficiaries, development of technical specifications, technical support, reporting, and financial control of funds (UNDP) (US $75,000).

<u>Conversion of HCFC-22 in the manufacture of residential air-conditioning units</u>

Background

38. UNIDO submitted a project proposal for the conversion of HCFC-22 in the manufacturing of residential air-conditioning units to HFC-32 and R-454B, at the amount of US $11,710,018, plus agency support costs of US $819,701, as submitted.

39. The objective of the project is to phase out HCFC-22 in the residential AC manufacturing sector by:

(a) Adapting and redesigning the AC equipment to use a low-GWP alternative refrigerant;

(b) Convert the manufacturing enterprises to the alternative refrigerants through:

(i) Purchasing new manufacturing equipment where needed, without increasing production capacity;

(ii) Implementing safety systems for safe storage and handling of flammable refrigerants;

(iii) Providing TA for the redesign of new equipment to maintain or enhance energy efficiency;

(iv) Providing TA for the redesign of new equipment to ensure compliance with relevant international safety standards;

(v) Implementing working procedures for safe handling of flammable refrigerants; and

(vi) Obtaining safety certification to current international standards (e.g., European Union directives).

Project description

40. Five manufacturers (El-Araby, Fresh, Miraco, Power, and Unionaire), which are the only manufacturers of residential ACs in the country, and that participated in EGYPRA, would phase out their use of HCFC-22. While most of their residential AC equipment is sold locally, the enterprises also export to the Gulf and North Africa regions; they do not export to non-Article 5 countries. All five manufacturers are 100 per cent Article 5-owned except for Miraco, which has 37 per cent non-Article 5 ownership. Some manufacturers have an agreement with global AC suppliers and are therefore linked to them in the choice of design and components, which also affects their choice of refrigerant technology. Each manufacturer has one factory and all of them produce a full range of residential AC equipment and appliances. All five use HCFC-22 and R-410A, except Power, which only uses HCFC-22. None of the manufacturers were previously funded for conversion to HCFC technologies. Table 3 summarizes the status of manufacturing at the five enterprises and their consumption in 2016 to 2018:

Table 3. Status of manufacturing and HCFC-22 consumption at the five enterprises (mt)

Manufacturer	No. lines	Production details	2016	2017	2018
El-Araby	2	The two production lines operate with a different speed and cycle time. The leak test for the indoor units is done by charging a small amount of HCFC-22 and using a halogen leak detector.	275	198	212
Fresh	2	The two production lines have the same speed and the cycle time. Fresh use helium leak test chambers for the indoor units.	136	142	147
Miraco	3	The three production lines have the same speed and the cycle time. Miraco use Helium leak test chambers for the indoor units.	396	359	366

Manufacturer	No. lines	Production details	2016	2017	2018
Power	1	The production line operates with a cycle time of approximately 70s. The same line is used for the production of indoor and outdoor units. The leak test for the indoor units is done by charging a small amount of HCFC-22 and using a halogen leak detector.	50	43	45
Unionaire	2	The production lines operate with a cycle time of approximately 40s. The leak test for the indoor units is done by charging a small amount of HCFC-22 and using a halogen leak detector.	600	360	240

41. The following process and test areas in the manufacturing facility will be affected by the conversion to flammable refrigerants: leak test (indoor unit production line), vacuum systems (outdoor unit production line), refrigerant storage and supply systems, refrigerant charging systems (outdoor production line), welding equipment (outdoor production line), final leak detection (outdoor production line), run test areas (outdoor production line), and laboratory test chambers. The general factory infrastructure, such as support for ventilation systems, electrical grounding and antistatic protection, were considered under the responsibility of each manufacturer.

Project costs

42. Table 4 shows a summary of the equipment requested for the conversion and incremental capital cost (ICC) for each manufacturer. The total ICC is US $5,085,410, with any cost associated with heat exchanger modifications borne by the manufacturers.

Table 4. ICC for the five enterprises, as submitted (US $)

Process area and equipment	Manufacturer					Total
	El-Araby	Fresh	Miraco*	Power	Unionaire	
Refrigerant supply system (supply pump, supply pipeline(s), and gas sensors)	81,000	118,000	74,340	76,000	118,000	467,340
Indoor manufacturing line (charging equipment, refrigerant recovery station, safety systems and ventilation)	84,000	0	0	0	168,000	252,000
Outdoor manufacturing line (charging equipment, refrigerant recovery station, safety systems and ventilation, leak detection, and process couplers)	473,500	405,000	494,550	248,000	535,000	2,156,050
Run test area (test bay modifications, safety systems and ventilation)	122,000	82,000	77,490	30,000	100,000	411,490
Laboratory chambers (refrigerant recovery station, safety systems and ventilation)	183,000	61,000	38,430	61,000	61,000	404,430
General (spare parts)	30,000	30,000	28,350	7,500	30,000	125,850
Engineering, Installation, certification and training	143,000	98,000	118,440	77,000	138,000	574,440
TA	50,000	50,000	31,500	50,000	50,000	231,500
Contingency	116,650	84,400	86,310	54,950	120,000	462,310
Total	**1,283,150**	**928,400**	**949,410**	**604,450**	**1,320,000**	**5,085,410**

*After taking into account 37 per cent non-Article 5 ownership.

43. Incremental operating costs (IOCs) based on a year of operation with the new refrigerant were calculated taking into consideration the company's eligible consumption, calculated as the 2016-2018 average, and the IOC threshold of US $6.30/kg specified in decision 74/50.

Table 5. Total cost for the conversion at the five manufacturers (US $)

Enterprise	mt	ODP tonnes	ICC (US $)	IOC (US $)	Total (US $)	CE (US $kg)
El-Araby	228.45	12.56	1,283,150	1,439,222	2,722,372	11.92
Fresh	141.67	7.79	928,400	892,502	1,820,902	12.85
Miraco*	373.67	20.55	949,410	1,483,084	2,432,494	6.51
Power	46.00	2.53	604,450	289,800	894,250	19.44
Unionaire	400.00	22.00	1,320,000	2,520,000	3,840,000	9.60
Total	**1,189.78**	**65.44**	**5,085,410**	**6,624,608**	**11,710,018**	**9.84**

* After taking into account 37 per cent non-Article ownership.

44. The project would necessitate the revision of the Agreement for stage II of the HPMP, which was approved at the 79th meeting.

SECRETARIAT’S COMMENTS AND RECOMMENDATION

COMMENTS

Progress report on the implementation of the first tranche of the HPMP

PU foam manufacturing sector

45. While noting the considerable progress in implementing the conversions of the PU foam manufacturing sector, including that all equipment required by the assisted enterprises had been purchased, the Secretariat noted that not all the equipment had been delivered and that the Government had banned the import, use and export of HCFC-141b in bulk and export of HCFC-141b contained in pre-blended polyols by 1 January 2020. UNDP confirmed that any equipment that had not yet been delivered, was expected to be delivered by 31 December 2019. Installation of equipment would require that foam manufacturing ceases while installation, commissioning and optimization of the new equipment is undertaken; accordingly, the enterprises would be able to comply with the ban. UNDP further confirmed that the HCFC-based equipment would be dismantled and rendered unusable.

Conversion of HCFC-22 in the manufacture of residential air-conditioning units

Technology selection

46. At the 79th meeting, the Secretariat was unable to assess the incremental cost of the proposed conversion of the sector as, at that time, the enterprises decided to assess the results of the still ongoing EGYPRA and PRAHA-II demonstration projects before they made their technology selection.

47. The Secretariat noted that the proposal built on the lessons from EGYPRA in selecting the technologies the enterprises will convert to, as well as being informed by the 2018 Refrigeration Air-Conditioning and Heat Pumps Technical Options Committee assessment report,[15] and other technical evaluations. If successfully implemented, the project would further Egypt’s compliance with the Montreal Protocol control obligations and would help avoid the introduction of high-GWP alternatives (i.e., R-410A) into the residential AC market.

[15] Available at https://ozone.unep.org/sites/default/files/2019-04/RTOC-assessment-report-2018_0.pdf

48. In line with decision 74/20(a)(iii), the Secretariat requested information from the suppliers on how and when an adequate supply of HFC-32 (GWP = 675) and R-454B (GWP = 490), and the necessary components (in particular, compressors) would be available to the country. UNIDO indicated that HFC-32 and HFC-32 compressors are readily available, including compressors suitable for use at high ambient temperatures; local suppliers indicated they would be able to provide HFC-32 compressors by the end of 2020. In contrast, the supply chain for R-454B refrigerants and components is not yet fully established: there is limited supply of R-454B refrigerant, and there are no R-454B compressors on the market yet. It was expected that both the refrigerant gas and compressors would become available in non-Article 5 countries in 2023, and in Egypt two or three years later. Given that R-454B is not available in the local market, and that this situation is likely to persist beyond the completion of stage II of the HPMP, the Secretariat was unable to consider the costs of converting to R-454B. Accordingly, it was agreed that the incremental costs would be determined based on a transition to HFC-32; however, the enterprises would have the flexibility to choose to also manufacture R-454B-based equipment once the technology becomes available.

Incremental cost

49. The discussions on ICCs related to the cost of charging machines; the number of ultrasonic welding machines needed; the eligibility of the request of process couplers that are required irrespective of the refrigerant used; costs related to the laboratories, including gas monitoring, ventilation, and whether a recovery machine was needed; the cost of a helium leak detection system, given the practice at two of the enterprises to test the indoor units for leaks with HCFC-22; and the price of spare parts, project engineering, installation and training, and safety audits. In addition, the TA requested at each enterprise to maintain or enhance energy efficiency was not eligible, and the TA to ensure safety compliance was already included in the agreed costs for installation and training. However, in line with the suggestion by the independent technical review of the project and the findings of EGYPRA, the Secretariat considered further assistance would be needed to optimize the performance of the equipment manufactured to ensure it can compete with R-410A-based equipment on the market.

50. After taking into account the ineligibility of equipment purchased after 21 September 2007, the agreed ICC for the five enterprises was adjusted from US $5,085,410 to US $4,253,197, as shown in Table 6.

Table 6. Agreed ICC for the five enterprises (US $)

Process area and equipment	Manufacturer					Total
	El-Araby	**Fresh**	**Miraco**	**Power**	**Unionaire**	
Refrigerant supply system	81,000	118,000	74,340	40,000	118,000	431,340
Indoor manufacturing line	65,000	0	0	0	130,000	195,000
Outdoor manufacturing line	328,500	304,500	406,035	216,500	448,500	1,704,035
Run test area	122,000	82,000	77,490	30,000	100,000	411,490
Laboratory chambers	71,000	31,000	32,130	31,000	31,000	196,130
Spare parts	15,000	15,000	14,175	7,500	15,000	66,675
Engineering, Installation, certification and training	112,000	72,000	70,560	62,000	112,000	428,560
Product design and optimization	150,000	75,000	94,500	50,000	150,000	519,500
Contingency	68,250	55,050	60,417	32,500	84,250	300,467
Total ICC	**1,012,750**	**752,550**	**829,647**	**469,500**	**1,188,750**	**4,253,197**

51. IOCs were agreed based on the average charge per unit (1.30 kg/unit), a 30 per cent reduction in charge when converting from HCFC-22 to HFC-32, the difference in price of HCFC-22 (US $2.95/kg) and HFC-32 (US $7.94/kg) and additional costs related to safety and possible minor differences in the price of HFC-32 compressors suitable for use at high ambient conditions (US $3.65/unit), resulting in an IOC of US $6.18/kg.

52. In addition, at the 79th meeting, it was agreed that the costs of the PMU might be increased if a residential AC manufacturing sector proposal was approved as part of stage II[16], which UNIDO had inadvertently omitted from its project proposal; additional funding of US $175,000 for the PMU was agreed.

53. On that basis, the total costs of the project were agreed at US $10,926,623, as shown in Table 7.

Table 7. Agreed costs for the conversion at the five manufacturers (US $)

Enterprise	mt	ODP tonnes	ICC (US $)	IOC (US $)	Total (US $)	CE/kg
El-Araby	228.45	12.56	1,012,750	1,411,809	2,424,559	10.61
Fresh	141.67	7.79	752,550	875,502	1,628,052	11.49
Miraco*	373.67	20.55	829,647	1,454,835	2,284,482	6.11
Power	46.00	2.53	469,500	284,280	753,780	16.39
Unionaire	400.00	22.00	1,188,750	2,472,000	3,660,750	9.15
PMU					175,000	
Total	**1,189.78**	**65.44**	**4,253,197**	**6,498,426**	**10,926,623**	**9.18**

* After taking into account 37 per cent non-Article ownership

Sustainability of the conversion

54. All the enterprises except Power manufacture both HCFC-22 and R-410A-based units on their manufacturing lines; in particular, each line (with the exception of the line at Power) can be used to manufacture either HCFC-22-based or R-410A-based equipment. Given that the enterprises manufacture R-410A-based equipment, and that such equipment is readily available on the international market, is relatively cheap, and is also imported into the country, the Secretariat considered that an enabling framework to ensure the sustainability of the phase-out would be required.

55. The Secretariat and UNIDO discussed in detail options for such an enabling framework. In particular, the Secretariat suggested that such a framework could include implementing a higher tariff on the import of R-407C and R-410A-based residential AC equipment, a tax on such equipment that is locally manufactured that is consistent with the tariff, and a subsidy for the low-GWP equipment. UNIDO informed that while the Government was considering a range of policy measures, such measures would likely not be exclusively in the purview of the EEAA and the NOU, and as implementing such measures would require domestic consultations, the Government needed additional time to select the measures. Accordingly, it was agreed that the Government of Egypt commits to adopt and enforce adequate regulatory measures, in conjunction with the progress of the conversion project, to: ensure full control of R-410A/R-407C-based AC residential equipment, imported or placed in the local market; and secure the uptake of the selected alternative technology by the local market.

56. An update on the status of implementation of those measures would be presented when the third tranche of the stage II of the HPMP was submitted. The Secretariat's review of the tranche request would take into account the progress made in implementing a framework for the enabling environment.

57. In addition, it was agreed that the five enterprises would commit to actively participate in efforts to promote the market acceptance of the residential AC equipment based on the agreed technology, and commit to ensuring that their manufacturing of R-410A-based equipment for the local market progressively decreases until the enterprises only manufacture equipment for the local market with the agreed technology, or a lower-GWP technology.

58. Regarding the possible future manufacture of both HFC-32-based and R-454B-based equipment, the Secretariat noted that once R-454B becomes available, its cost may be higher than that of HFC-32. Accordingly, there may be a risk that R-454B equipment that needs servicing may be topped up with

[16] Paragraph 56 of UNEP/OzL.Pro/ExCom/79/32.

HFC-32, the principal component of R-454B, rather than the blend itself. UNIDO clarified that while the consequences for the piece of equipment may be limited, such a practice might impact the equipment reliability, in part given the higher discharge temperature of HFC-32. Nullification of the manufacturer's warranty could be considered to discourage such potential practice, as well as the development of special charging ports for R-454B, if possible.

59. Noting that the conversion of the five enterprises would result in the conversion of the entire residential AC manufacturing sector, it was agreed that the Government of Egypt would ban the import and manufacture of HCFC-22-based residential AC equipment by 1 January 2023, in line with decision 79/25.

60. Regarding the future eligibility of the enterprises, there was a common understanding that the five enterprises would not be eligible for further funding from the Multilateral Fund to phase out HCFCs or R-410A. In addition, the Secretariat understands that, in line with paragraphs 17 and 18 of decision XXVIII/2, the enterprises would also not be eligible to phase-down their HFC-32 consumption, and that this understanding was shared with the Government of Egypt and the enterprises.

Impact on the climate

61. The replacement of HCFC-22 by HFC-32 in the AC sector will result in avoiding the emissions of 2,223,435 mt CO_2-eq. (i.e. from the baseline of 5,797,387 mt CO_2-eq. emissions to 3,573,952 mt CO_2-eq.), based on the revised multilateral fund climate impact indicator (MCII).

Co-financing

62. The total agreed cost of the conversion of the residential AC sector is US $10,926,623; other additional costs, such as investments for conversion of heat-exchanger facilities (if needed) would be borne by the enterprises. The Government of the Egypt would provide co-financing through in-kind support to implement the regulatory and policy support measures needed to help ensure the sustainable conversion of the residential AC sector to low-GWP alternatives.

Revision to HPMP Agreement

63. In line with decision 79/34(d), the Government proposed to revise the Agreement for stage II of the HPMP. Based on the project timeline, it was agreed to divide the funding associated with the project to convert the five residential AC manufacturing enterprises across the 2019, 2021 and 2023 tranches; to change the 2023, 2024, and 2025 target specified in row 1.2 in line with the footnote to Appendix 2-A agreed at the 79th meeting;[17] to deduct 65.44 ODP tonnes of HCFC-22 from the country's remaining consumption eligible for funding, to update the target for controlled use in paragraph 1 to 115.54 ODP tonnes, and to add a new paragraph 17 to reflect that the Agreement had been updated, as shown in Annex II to the present document. The full updated Agreement will be appended to the final report of the 84th meeting.

Sustainability of the HCFC phase-out

64. The Government of Egypt has promulgated regulations that support the conversions in the PU foam manufacturing sector, including a ban on the import of HCFC-141b contained in pre-blended polyols as of 1 January 2018, and the ban on the import, use and export of HCFC-141b in bulk and the export of HCFC-141b contained in pre-blended polyols, which will be effective by 1 January 2020. The Government has further committed to ban the use of HCFCs and blends of HCFCs in the manufacture of XPS foam by

[17] Maximum allowable total consumption of Annex C, Group I substances would be further reduced by no more than 10 ODP tonnes upon approval of a domestic air-conditioning sector plan as part of stage II.

1 January 2023; ban the import of HCFC-142b and blends of HCFC-142b by 1 January 2023; and, with approval of the project to convert the five residential AC manufacturing sector, ban the import and manufacture of HCFC-22-based residential AC equipment by 1 January 2023; and committed to ensure full control of R-410A- and R-407C-based AC residential equipment, imported or placed in the local market; and committed to secure the uptake of the HFC-32 and, should the enterprises so decide once the technology becomes available, R-454B technology by the local market.

Conclusion

65. The implementation of the HPMP is progressing, the country's import licensing and quota system is operational, and the verified consumption is below the 2018 targets. The conversions in the PU foam sector are progressing, and all enterprises will be able to comply with 1 January 2020 ban on the import, use and export of HCFC-141b in bulk and the export of HCFC-141b contained in pre-blended polyols. The level of disbursement is 33 per cent. The activities planned under the second tranche will enable the conversion of the XPS foam manufacturing sector, to be completed with funding from the third tranche, and will further build the capacity of customs and enforcement officers, and strengthen the servicing sector, thereby helping ensure that the country continues to meet its compliance obligations under the Protocol. Absent a project to convert the residential AC manufacturing sector to low-GWP alternatives, four of the five enterprises would likely start to exclusively manufacturing R-410A equipment on their existing lines; the project, including the framework for an enabling environment, and the associated policy measures, will be critical to avoiding this outcome and sending a signal to the market to convert to low-GWP technology, which could bend the trajectory of market transformation in this sector in favour of low-GWP alternatives.

RECOMMENDATION

66. The Executive Committee may wish to consider:

(a) Noting the progress report on the implementation of the first tranche of stage II of the HCFC phase-out management plan (HPMP) for Egypt;

(b) Approving the project for the conversion of El-Araby, Fresh, Miraco, Power, and Unionaire from HCFC-22 to HFC-32 and, should the enterprises so decide once the technology becomes available, R-454B, used in the manufacture of residential air-conditioning (AC) units in the amount of US $10,926,623 plus support costs of US $764,864 for UNIDO;

(c) Deducting 65.44 ODP tonnes of HCFC-22 from the remaining HCFC consumption eligible for funding;

(d) Noting the commitment of the Government of Egypt to a sustained level of 115.54 ODP tonnes by 1 January 2025 in compliance with the Montreal Protocol schedule;

(e) Noting:

(i) The commitment of the Government of Egypt to:

a. Ban the import and manufacture of HCFC-22-based residential AC equipment by 1 January 2023;

b. Ensure full control of R-410A- and R-407C-based AC residential equipment, imported or placed in the local market; and

c. Secure the uptake of the HFC-32 and, should the enterprises so decide once the technology becomes available, R-454B technology by the local market;

(ii) The commitment of El-Araby, Fresh, Miraco, Power, and Unionaire to actively participate in efforts to promote the market acceptance of the residential AC equipment based on the agreed technology, and to ensure that their manufacturing of R-410A-based equipment for the local market progressively decreased until the enterprises only manufacture equipment for the local market with the agreed technology, or a lower-GWP technology;

(f) That the Secretariat had updated Appendix 2-A of the Agreement between the Government of Egypt and the Executive Committee, based on the approval of the project proposal referred to in sub-paragraph (b) above, and the deduction of HCFC tonnage referred to in sub-paragraph (c) above, updated the target for controlled use in paragraph 1 to 115.54 ODP tonnes, and that a new paragraph 17 had been added to indicate that the updated Agreement superseded that reached at the 79th meeting, as contained in Annex II to the present document; and

(g) Approving the second tranche of stage I of the HPMP for Egypt, and the corresponding 2019-2022 tranche implementation plan, at the amount of US $6,991,764, consisting of US $4,668,214, plus agency support costs of US $326,775 for UNIDO; US $1,836,750, plus agency support costs of US $128,573 for UNDP; US $279,500, plus agency support costs of US $33,394 for UNEP; and US $207,300, plus agency support costs of US $26,949 for the Government of Germany.

Annex I

EGYPRA

1. Nineteen custom-built split unit prototypes with dedicated compressors provided by a number of enterprises were tested at locally available accredited labs with refrigerants provided by Arkema, Chemours, Daikin, and Honeywell. Tests were repeated for optimization.

2. The results show that there is a potential to improve the capacity and energy efficiency of the prototypes working with alternatives to HCFC-22 and R-410A (with higher improvements for R-410A alternatives). These improvements are dependent on the availability and selection of the right components for units that can deliver the required performance.

3. There is a need for capacity building to enable the manufacturers to design, optimize, and test units with flammable refrigerants in order to improve the performance and meet energy efficiency standards, and to upgrade their testing facilities both in terms of instrumentation as well as to handle flammable refrigerants. Test results show that all refrigerants used in the project are viable alternatives from a thermodynamic point of view; however, when compared to the Minimum Energy Performance Standards for Egypt, results show there are challenges for the industry to provide high efficiency AC units meeting stringent requirements in the coming years. Moreover, the viability in terms of the other criteria, like compatibility, commercial availability, safety, and cost need to be further researched.

4. The Secretariat sought clarification on whether the findings and conclusions of EGYPRA were the same as other testing programmes that have similarly tested low-GWP alternatives in the AC manufacturing sector, including demonstration projects funded by the Multilateral Fund. Table 1 compares the design criteria, testing protocols, refrigerants tested and constraints of four testing programmes: AREP-II[1], EGYPRA, ORNL[2], and PRAHA[3]:

Table 1. Comparison of PRAHA, EGYPRA, ORNL, and AREP-II testing programmes

<table>
<tr><th colspan="2">Programme</th><th colspan="4">PRAHA</th><th colspan="4">EGYPRA</th><th colspan="2">ORNL – Phase I (Mini-split AC)</th><th>AREP-II</th></tr>
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<tr><td>18 MBH</td><td>24 MBH</td><td>36 MBH</td><td>90 MBH</td><td>12 MBH</td><td>18 MBH</td><td>24 MBH</td><td>120 MBH</td><td>18 MBH R-22 eq.</td><td>18 MBH R-410a eq.</td></tr>
</table>

[1] AHRI Alternative Refrigerant Evaluation Program http://www.ahrinet.org/arep

[2] Abdelaziz 2015 Abdelaziz O, Shrestha S, Munk J, Linkous R, Goetzler W, Guernsey M and Kassuga T, 2015. "Alternative Refrigerant Evaluation for High-Ambient-Temperature Environments: R-22 and R-410A Alternatives for Mini-Split Air Conditioners", ORNL/TM-2015/536. Available at: https://www.energy.gov/sites/prod/files/2015/10/f27/bto_pub59157_101515.pdf .

[3] PRAHA Project Report: https://www.unenvironment.org/resources/report/promoting-lowgwp-refrigerants-air-conditioning-sectors-high-ambient-temperature

Programme		PRAHA	EGYPRA	ORNL – Phase I (Mini-split AC)	AREP-II
4	**Testing conditions**	ANSI/AHRI Standard 210/240 and ISO 5151 at T1, T3 and T3+ (50°C) and a continuity test for 2 hours at 52°C	EOS 4814 and 3795 (ISO 5151) T1, T2, and T3 conditions	ANSI/AHRI Standard 210/240 and ISO 5153 T3 (2010) condition	ANSI/AHRI 210/240, at T1, T3, and 125 °F
5	**Prototypes supplied and tests performed**	Prototypes built at six OEMs, test at Intertek	Prototypes built at eight OEMs, witness testing at OEM labs	ORNL, one supplier – soft optimization in situ	Individual suppliers, testing at own premises
6	**Refrigerants tested**	Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3	Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3, R-457A (ARM-32d)	Eq. to HCFC-22:N-20B, DR-3, ARM-20B, R-444B (L-20A), HC-290	Eq. to R-410A: HFC-32, DR-5A, DR-55, L-41-1, L-41-2, ARM-71a, HPR2A
		Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A)	Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A), ARM-71d	Eq. to R-410A: HFC-32, R-447A (L-41-1), DR-55, ARM-71d, HPR-2A	
		Final report end March 2016			
7	**Constraints**	To build new prototypes with dedicated compressors for the selected refrigerants fitting in the same box dimensions as the original design and comparing performance and efficiency to base models with HCFC-22 and R-410A units	To build new prototype with dedicated compressors for the selected refrigerants with the condition to meet same design capacities of the selected models in comparison to the HCFC-22 and R-410A units	To change some components of the two prototypes to accommodate the different refrigerants, within a “soft optimisation” process	-Drop-in; -Soft optimization by adjusting expansion device, adjusting charge amount, and changing type of oil; -One case of compressor speed adjustment using variable speed drives

*MBH = Thousand British thermal units

5. While EGYPRA is similar in design to the other projects it has the following distinctive features:

(a) EGYPRA is a programme of the HPMP designed to involve the local manufacturers in the decision making of the best refrigerant alternatives for their industry. The second phase of the programme will give manufacturers an insight of the optimization process;

(b) The programme involves more manufacturers, except for AREP, and tests more prototypes than the other three. The eight alternative refrigerants used covered the available refrigerants at the time the prototypes were built;

(c) EGYPRA was not focused only on high-ambient temperatures but across the full range of temperatures that may be prevalent in Egypt; and

(d) The test results presented are more easily to explain the relationships between refrigerant, ambient temperature, equipment application, and performance.

6. EGYPRA was not compared against the final report on the demonstration project at AC manufacturers to develop window and packaged air conditioners using refrigerants with low GWP in Saudi Arabia nor with the final report on the demonstrative project for HCFC-22 phase-out in the manufacturing of commercial air-conditioning equipment at Industrias Thermotar Ltda in Colombia.

Annex II

TEXT TO BE INCLUDED IN THE DRAFT UPDATED AGREEMENT BETWEEN THE GOVERNMENT OF EGYPT AND THE EXECUTIVE COMMITTEE OF THE MULTILATERAL FUND FOR THE REDUCTION IN CONSUMPTION OF HYDROCHLOROFLUOROCARBONS IN ACCORDANCE WITH STAGE II OF THE HCFC PHASE-OUT MANAGEMENT PLAN

(Relevant changes are in bold font for ease of reference)

1. This Agreement represents the understanding of the Government of Egypt (the "Country") and the Executive Committee with respect to the reduction of controlled use of the ozone depleting substances (ODS) set out in Appendix 1-A ("The Substances") to a sustained level of **115.54** ODP tonnes by 1 January 2025 in compliance with Montreal Protocol schedule.

17. **This updated Agreement supersedes the Agreement reached between the Government of Egypt and the Executive Committee at the 79th meeting of the Executive Committee.**

APPENDIX 2-A: THE TARGETS, AND FUNDING

Row	Particulars	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
1.1	Montreal Protocol reduction schedule of Annex C, Group I substances (ODP tonnes)	347.64	347.64	347.64	251.08	251.08	251.08	251.08	251.08	125.54	n/a
1.2	Maximum allowable total consumption of Annex C, Group I substances (ODP tonnes)	347.64	289.70	289.70	251.08	251.08	251.08	**241.08**	**241.08**	**115.54**	n/a
2.1	Lead IA (UNIDO) agreed funding (US $)	3,356,641	0	**4,668,214**	0	**4,664,196**	0	**4,039,413**	0	195,000	**16,923,464**
2.2	Support costs for Lead IA (UNIDO) (US $)	234,965	0	**326,775**	0	**326,494**	0	**282,759**	0	13,650	**1,184,642**
2.3	Cooperating IA (UNDP) agreed funding (US $)	1,042,352	0	1,836,750	0	816,620	0	0	0	0	3,695,722
2.4	Support costs for Cooperating IA (UNDP) (US $)	72,965	0	128,573	0	57,163	0	0	0	0	258,701
2.5	Cooperating IA (UNEP) agreed funding (US $)	230,000	0	279,500	0	260,000	0	180,000	0	105,500	1,055,000
2.6	Support costs for Cooperating IA (UNEP) (US $)	27,480	0	33,394	0	31,064	0	21,506	0	12,605	126,050
2.7	Cooperating IA (Germany) agreed funding (US $)	0	0	207,300	0	0	0	0	0	0	207,300
2.8	Support costs for Cooperating IA (Germany) (US $)	0	0	26,949	0	0	0	0	0	0	26,949
3.1	Total agreed funding (US $)	4,628,993	0	**6,991,764**	0	**5,740,816**	0	**4,219,413**	0	300,500	**21,881,486**

Row	Particulars	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
3.2	Total support costs (US $)	335,410	0	**515,690**	0	**414,721**	0	**304,265**	0	26,255	**1,596,342**
3.3	Total agreed costs (US $)	4,964,403	0	**7,507,454**	0	**6,155,537**	0	**4,523,678**	0	326,755	**23,477,828**
4.1.1	Total phase-out of HCFC-22 agreed to be achieved under this Agreement (ODP tonnes)										**135.97**
4.1.2	Phase-out of HCFC-22 to be achieved in the previous stage (ODP tonnes)										6.13
4.1.3	Remaining eligible consumption for HCFC-22 (ODP tonnes)										**98.09**
4.2.1	Total phase-out of HCFC-123 agreed to be achieved under this Agreement (ODP tonnes)										0
4.2.2	Phase-out of HCFC-123 to be achieved in the previous stage (ODP tonnes)										0
4.2.3	Remaining eligible consumption for HCFC-123 (ODP tonnes)										0.11
4.3.1	Total phase-out of HCFC-141b agreed to be achieved under this Agreement (ODP tonnes)										33.92*
4.3.2	Phase-out of HCFC-141b to be achieved in the previous stage (ODP tonnes)										95.69
4.3.3	Remaining eligible consumption for HCFC-141b (ODP tonnes)										0
4.4.1	Total phase-out of HCFC-142b agreed to be achieved under this Agreement (ODP tonnes)										16.36
4.4.2	Phase-out of HCFC-142b to be achieved in the previous stage (ODP tonnes)										0
4.4.3	Remaining eligible consumption for HCFC-142b (ODP tonnes)										0
4.5.1	Total phase-out of HCFC-141b in imported pre-blended polyols agreed to be achieved under this Agreement (ODP tonnes)										26.16
4.5.2	Phase-out of HCFC-141b in imported pre-blended polyols to be achieved in the previous stage (ODP tonnes)										72.18
4.5.3	Remaining eligible consumption for HCFC-141b in imported pre-blended polyols(ODP tonnes)										0

* Including the phase-out of 4.4 ODP tonnes approved at the 76th meeting and herewith subsumed into this Agreement.
Note: Date of completion of stage I as per stage I Agreement: 31 December 2019.

EGYPRA – Promotion of Low-GWP Refrigerants for the Air Conditioning Industry in Egypt

2019

Report

Project supported by the Multilateral Fund of the Montreal Protocol

UNITED NATIONS ENVIRONMENT

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Disclaimer

While the information contained herein is believed to be accurate, it is of necessity presented in a summary and general fashion. The decision to implement one of the options presented in this document requires careful consideration of a wide range of situation-specific parameters, many of which may not be addressed by this document. Responsibility for this decision and all its resulting impacts rests exclusively with the individual or entity choosing to implement the option. UNIDO, UNEP, their consultants and the reviewers and their employees do not make any warranty or representation, either expressed or implied, with respect to the accuracy, completeness or utility of this document; nor do they assume any liability for events resulting from the use of, or reliance upon, any information, material or procedure described herein, including but not limited to any claims regarding health, safety, environmental effects, efficacy, performance, or cost made by the source of information.

Acknowledgement

We would like to acknowledge the assistance given by the government and the National Ozone Unit Officers of Egypt for their support in the implementation of the project phases and their assistance in facilitating communication with the different stakeholders.

We also acknowledge the independent International Technical Review Team that assist the project team in reviewing the process, results and the report of the project.

Prof. Roberto Peixoto (Brazil)
Prof. Walid Chakroun (Kuwait)
Dr. Omar Abdel Aziz (USA/UAE)

Acknowledgement also goes to the "Technology Providers" (Refrigerant and Compressor manufacturers) for providing components free of charge.

Refrigerant Providers: Arkema, Chemours, Daikin, and Honeywell.
Compressor providers: Emerson, Highly, and GMCC.

Also the OEM manufacturers who built the prototypes and tested them at their own facilities. The OEMs are listed under item 1.6

Delta Construction Manufacturing (DCM)
Elaraby
Egyptian German Air Treatment Company (EGAT)
Fresh
Miraco
Power
Unionaire
Volta

Project Team

The National Ozone Unit – Ministry of Environment, Egypt: EGYPRA is funded by the HCFC Phase-out Management Plan (HPMP) of Egypt. The ministry team provided guidance and direction and participated at project meetings and discussions.

The Project Management: UN Environment and UNIDO provided overall management and coordination of the project, established the link with the technology providers, and oversaw the development of the report of the project. The Project was managed by Dr. Lamia Benabbas, Programme Officer – UNIDO and Mr. Ayman Eltalouny, International Partnership Coordinator, OzoneAction Programme – UN Environment

The Egyptian Organization for Standards: provided guidance on the Egyptian standards for testing as well as the minimum energy performance standards (MEPS).

The Technical Consultant, Dr. Alaa Olama advised OEMs during prototype design and construction. Devised testing methodology and testing TOR, consulted with OEMs to provide technical solutions for problems as they arose. The Technical Consultant witnessed-testing of all prototypes and baseline units, compiled testing data, and provided analysis of data.

The Coordination Consultant, Mr. Bassam Elassaad provided logistical support and coordination for the project and helped with writing of the final report.

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Acronyms

AHRI	Air Conditioning, Heating, and Refrigeration Institute
ANSI	American National Standards Institute
AREP	Alternative Refrigerant Evaluation Program
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
Btuh	Also denoted as BTU/h or B.t.u/hr = British Thermal Unit per Hour
BV	Burning Velocity
CAP	Capacity
CC	Cooling Capacity
CFC	Chloro Fluoro Carbon
COP	Coefficient of Performance
DB	Dry Bulb
DC	District Cooling
DX	Direct Expansion
EE	Energy Efficiency
EER	Energy Efficiency Ratio
EGYPRA	Egyptian Program for Promoting Low-GWP Refrigerant Alternatives
EN	European Norms (Standards)
EPA	Environmental Protection Agency (US)
GWP	Global Warming Potential
HAT	High Ambient Temperature
HC	Hydro Carbons
HCFC	Hydro Chloro Fluoro Carbon
HFC	Hydro Fluoro Carbon
HFO	Hydro Fluoro Olefins
HPMP	HCFC Phase-out Management Plan
HVACR	Heating, Ventilation, Air Conditioning and Refrigeration
HX	Heat Exchanger
IU	Indoor Unit
IEC	International Electrotechnical Commission
IPR	Intellectual Property Rights
ISO	International Standards Organization
Kg	Kilograms
kW	Kilowatts
LCCP	Life Cycle Climate Performance
LFL	lower Flammability Limit
MEPS	Minimum Energy Performance Standards
MOP	Meeting of Parties
MP	Montreal Protocol
NOU	National Ozone Unit
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substances
OEM	Original Equipment Manufacturer
PRAHA	Promoting Low-GWP Refrigerants for the Air Conditioning in HAT Countries
PSI	Pounds per Square Inch
RAC	Refrigeration and Air Conditioning
ROWA	UNEP Regional Office for West Africa
RTOC	Refrigeration, Air Conditioning, and Heat pump & Technical Options Committee

SCFM	Standard Cubic Foot per Minute
SHR	Sensible Heat ratio
SNAP	Significant New Alternative Policy
Tdb	Dry Bulb Temperature
Twb	Wet Bulb Temperature
TEAP	Technical & Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TF	Task Force
TWB	Wet Bulb Temperature
UNEP	United Nations Environment
UNIDO	United Nations Industrial Development Organization
USD	US Dollars
VC	Vienna Convention
VRF	Variable Refrigerant Flow
WB	Wet Bulb
WG	Working Group

Executive Summary

HCFCs are used extensively in the refrigeration and air conditioning industry, in particular in the air-conditioning industry. Parties to the Montreal Protocol, in their 21st meeting, adopted a decision concerning HCFCs and environmentally sound alternatives. The decision calls for further assessment and support work to enable parties to find the best ways of moving forward particularly for those with forthcoming compliance targets related to consumption of HCFC in the air-conditioning sector.

The aim of this program was to individually test custom-built AC split unit prototypes and central unit prototypes, to operate with alternative refrigerants and compare their performance against baseline units. Those baseline units are either HCFC-22 or R-410A. The list of refrigerants used and the split unit categories tested is as per the table below. The project involved building and testing 19 custom built split unit prototypes with dedicated compressors provided by Emerson, GMCC, and Hitachi Highly, and 16 base units by five OEMs. The refrigerants were provided by Arkema, Chemours, Daikin, and Honeywell. All the prototypes and the base units were tested at locally available accredited labs at the time the tests were conducted and witnessed by the project's Technical Consultant who also advised the OEMs during the manufacturing stage. Tests were repeated for optimization by tweaking some of the components. A total of 140 witnessed tests were performed. The central units were built but could not be tested due to lack of locally accredited available labs.

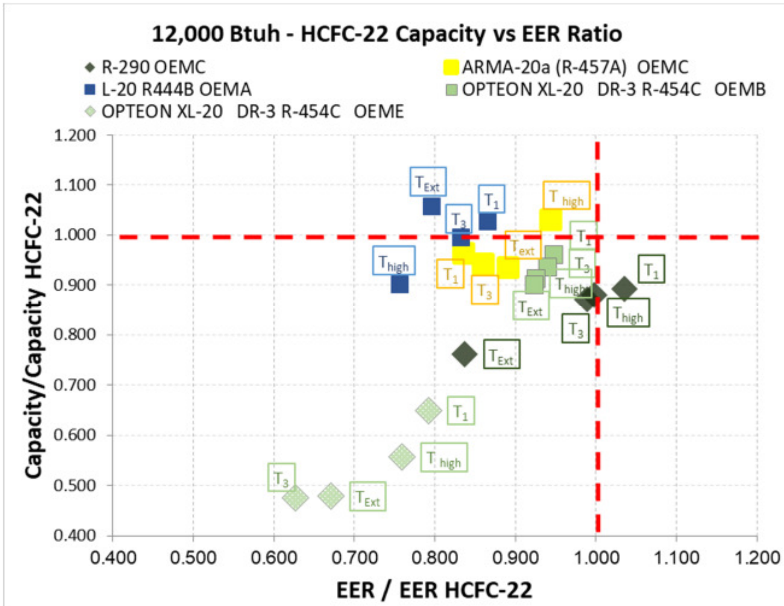
		Split system (mini-split)			Central 120,000 Btuh	
	Replacement for	**12,000 Btuh**	**18,000 Btuh**	**24,000 Btuh**	**Std. coil**	**micro channel**
HC-290	HCFC-22					
HFC-32	R-410A					
R-457C (Arkema ARM-20a)	HCFC-22					
R-459A (Arkema ARM -71a)	R-410A					
R-454C (Chemours DR-3)	HCFC-22					
R-454B (Chemours DR-5A)	R-410A					
R-444B (Honeywell L-20)	HCFC-22					
R-447A (Honeywell L-41)	R-410A					
HCFC-22 baseline						
R-410A baseline						

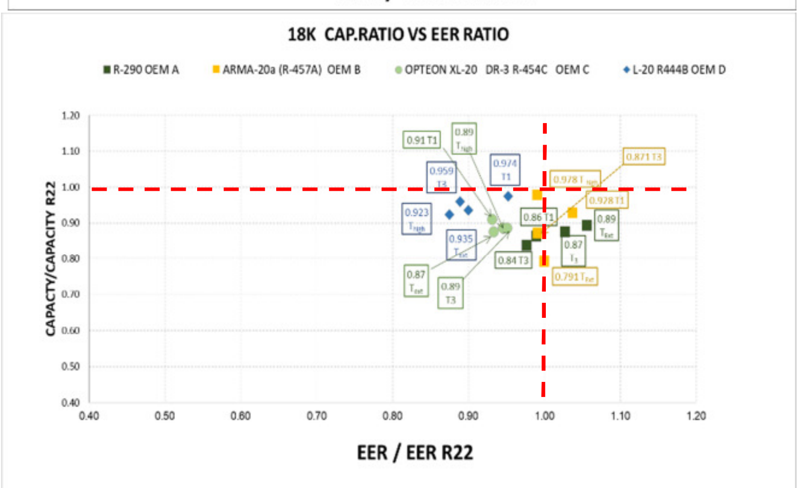
The units were tested at four ambient temperatures: T_1 (35 °C) and T_3 (46 °C) with indoor dry bulb/wet bulb temperatures of 27/19 °C and 29/19 °C respectively, plus two other ambient temperatures of 50 °C termed as T_{High} and 55 °C termed as $T_{Extreme}$ at ISO 5151 specified indoor dry bulb/wet bulb temperature of 32/23 °C (maximum testing condition in ISO 5151). These indoor temperatures are different from the ones used by other testing programs such as AREP and ORNL. The test results gave higher capacities at T_{High} than at T_3.

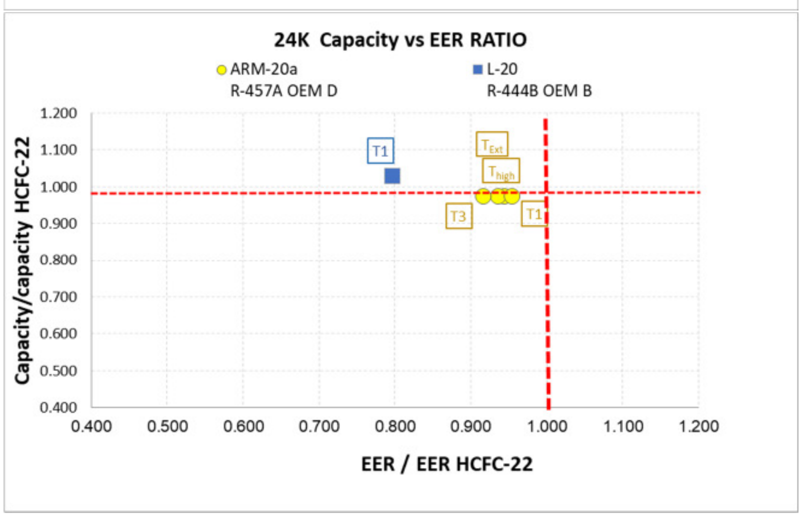
The casual reading of the results may establish confusion, even among specialists, in relation to the increase in capacity and EER at T_{High} compared to T_3. This result is not witnessed in other similar research projects; however, by understanding the impact of changing the dry bulb and wet bulb indoor testing conditions i.e. T_{high} (outdoor 50/24 ^{O}C, indoor 32/24 ^{O}C) compared to T_3 (outdoor 46/24 ^{O}C, indoor 29/19 ^{O}C), the results can be explained. These results were randomly double checked through a simulation exercise. The additional exercise to review the results delayed publishing results.

The test results are presented in comparison to the baseline units and color coded to denote the performance over or below the performance of the comparative baseline units. Scattered charts are plotted for the capacity ratio vs EER ratio for the prototypes vs the baseline units for each of the three unit categories and for the HCFC-22 alternatives and the R-410A alternatives. The red lines denote performance comparable to the base unit

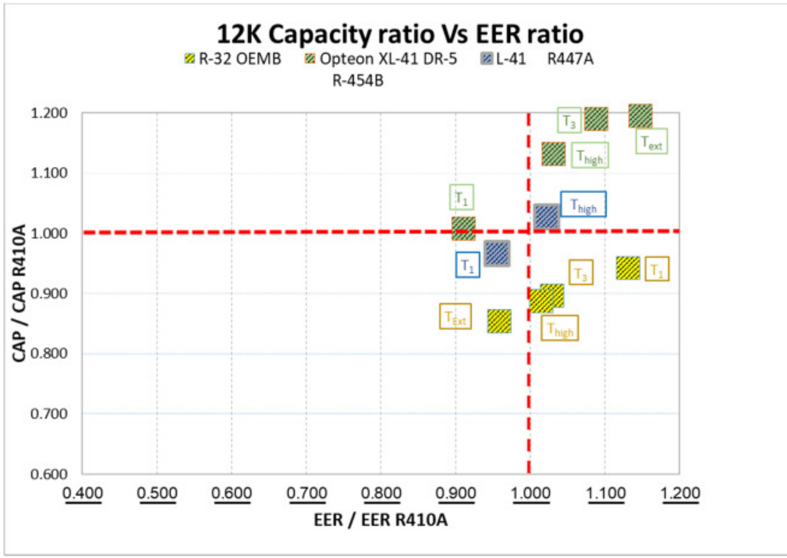
HCFC-22 alternatives

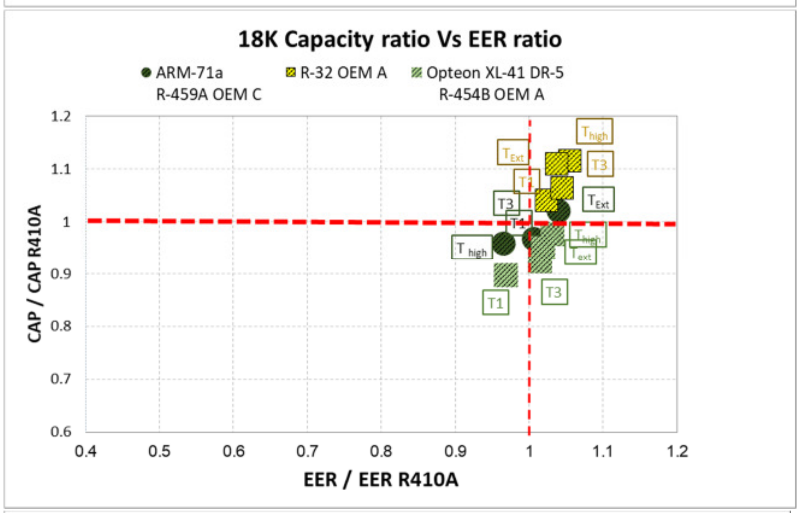


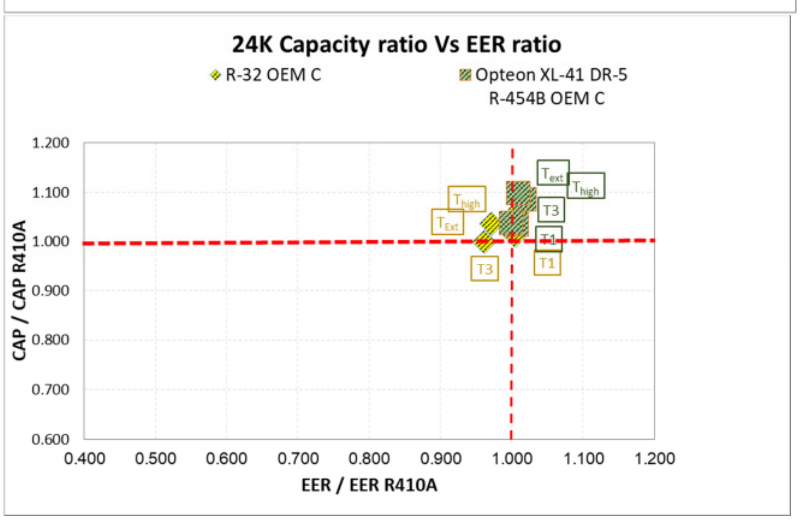




R-410A alternatives







Test results for HCFC-22 alternatives refrigerants demonstrate that:

- Several refrigerant alternatives show 60%, or above, chance for capacity matching or improvement across all categories and at different testing temperatures.
- Most refrigerant alternatives show 50%, or above, chance for EER improvement across all categories and at different testing temperatures.

Test results for R-410A alternatives refrigerants demonstrate that:

- All refrigerants showed improvement in capacity by 25 % to 67 %
- All refrigerants showed improvement in EER by 67 % to 75 %

The results show that there is a potential to improve the capacity and energy efficiency of the prototypes working with alternatives to HCFC-22; however, the potential for improvements for the prototypes working with alternatives to R-410A is better. This conclusion is in line with the outcome of other testing projects shown in Annex 4 and is based on the percentage of test results that were within plus or minus 10% of the results from testing the baseline refrigerants in the same category of equipment. This improvements are dependent on the availability and selection of the right components for units that can deliver the required performance while still be commercially viable.

An outcome of the project is a need for capacity building to enable the participating OEMs to design, optimize, and t test units with flammable refrigerants in order to improve the performance and meet the energy efficiency standards. There is a need to upgrade their testing facilities both in terms of instrumentation as well as to handle flammable refrigerants (refer to Annex 3 for a description of the OEM labs).

Test results show that all refrigerants used in the project are viable alternatives from a thermodynamic point of view; however, when compared to MEPS (Minimum Efficiency Performance Standards) for Egypt - see chapter 4 - results show there are challenges for the industry to provide high efficiency AC units meeting stringent requirements in the coming years. Moreover, the viability in terms of the other criteria like compatibility, commercial availability, safety, and cost among others needs to be further researched.

Chapter 1

1. Introduction

HCFCs are used extensively in the refrigeration and air conditioning industry, in particular in the air-conditioning industry. Parties to the Montreal Protocol, in their 21st meeting, adopted a decision concerning HCFCs and environmentally sound alternatives. The decision calls for further assessment and support work to enable parties to find the best ways of moving forward particularly for those with forthcoming compliance targets related to consumption of HCFC in the air-conditioning sector.

The PRAHA project (*Promoting Low-GWP Refrigerant Alternatives for the Air Conditioning Industry in High Ambient Temperature Countries*) was a pioneer project in testing specially built prototypes by local industries in the Middle East and West Asia region using alternatives refrigerants.

Manufacturers of residential and commercial air conditioning equipment in Egypt met with the Montreal Protocol implementing agencies in July 2014 and agreed on participating in a project to build and test prototypes using various HCFC alternatives at preset conditions in order to compare the performance and efficiency of those refrigerant alternatives.

The project's key elements are to:

a) Asses available low-GWP refrigerant alternatives by building, optimizing, testing and comparing prototypes with those alternatives;
b) Asses local Energy Efficiency (EE) standards and codes and the effect of using low-GWP refrigerant alternatives on those standards;
c) Promoting technology transfer by examining and facilitating technology transfer through the HPMP.

The last two elements are part of the Egyptian HPMP and are not included in this report.

1.1. Egypt HPMP

Egypt's starting point for aggregate reductions in its HCFC consumption is the same as its HCFC baseline consumption of 386 ODP tonnes (ODPt). The analysis of the data by substance and by sector showed that HCFC-22 is used almost entirely in the RAC sector and is the most predominant ODS in metric terms. However, in terms of ODS the use of HCFC-141b is significant, being 35% of the total baseline consumption. Egypt has committed to reduce its consumption by 25% by 2018. The 35% reduction on January 1, 2020 will take the consumption down to 251 ODPt.

The air conditioning manufacturing sub-sector accounts for about 35% of the HCFC-22 consumption. About 56% is used for servicing with RAC manufacturers accounting for the majority of this service consumption, while independent service companies account for just 3% of the HCFC-22 consumption.

The important consumption of HCFC-22 by local AC manufacturers, especially in the RAC sector, is the reason for adopting a project for testing locally built prototypes using low-GWP alternatives in Egypt. The program has been given the name EGYPRA (*Promotion of Low-GWP Refrigerants for the Air-Conditioning Industry in Egypt)*

1.2. Project Objectives

The aim of the program is to individually test especially made prototype split units and central units, to operate with alternative refrigerants and compare their performance against baseline units. Those baseline units are with either HCFC-22 or R-410A refrigerants.

The project objectives were decided upon in agreement with the local stakeholders and can be summarized as follows:

- Orient the Egyptian air conditioning manufacturers to the new medium and low-GWP refrigerants including those with low and high flammability;
- Support technical and policy decisions regarding long-term HCFC alternatives for the air-conditioning industry as part of the of Egypt's HPMP;
- Streamline the HCFC phase-out program with the Energy Efficiency work in Egypt;
- Promote the introduction of relevant standards/codes that ease the adoption of alternatives needing special safety or handling considerations;
- Exchange the experience with other relevant initiatives and programs which aim at addressing long term alternatives;
- Assess the capacity building and training needs for deploying low-GWP alternatives for different groups dealing or handling refrigerants in Egypt.

The outcomes from the above objectives are not presented in this report which only presents the results of the tests that were carried out for the various prototypes

1.3. Selection of Alternative Refrigerants

The selection of the alternative refrigerants was based on the following aspects which are derived from decision XXIII/9 of the Meeting of Parties (MOP):

I. Commercially available;
II. Technically proven;
III. Environmentally sound;
IV. Economically viable and cost effective;
V. Safety consideration;
VI. Easy to service and maintain.

EGYPRA took into consideration the refrigerants that were tested by PRAHA and added new alternatives that were still at an early stage of development when PRAHA was launched in 2012 even though they were still not commercially available at the time the prototype building and testing was done. The refrigerants were selected to replace either HCFC-22 or R-410A as shown in the two tables below, in line with the other testing projects on alternative refrigerants. It is worth noting that EGYPRA is a larger testing program than PRAHA, since it tested 19 specially made split unit prototypes and 16 baseline units, a total 35 units. It also witness-tested all units at the manufacturers' labs. In all 140 tests were made including baseline refrigerants and eight low GWP refrigerants.

Table 1 List of HCFC-22 alternative refrigerants

Refrigerant	ASHRAE classification	GWP (100 years) – RTOC
HC-290	A3	5
R-444B Honeywell L-20A	A2L	310
R-454C Chemours Opteon XL-20	A2L	295
R-457A Arkema ARM-20a	A2L	251

Table 2 List of R-410A alternative refrigerants

Refrigerant	ASHRAE classification	GWP (100 years) – RTOC
HFC-32	A2L	704
R-447A Honeywell L-41-2	A2L	600
R-454B Chemours Opteon XL-41	A2L	510
R-459A Arkema ARM-71a	A2L	466

While not all the selected refrigerants are not commercially available or cost effective at present, they have all received "R" numbers as per ASHRAE standard 34.

1.4. Selection of Capacity Categories

The selection of prototypes to build took into consideration that the majority of the units produced in Egypt are of the mini-split type with capacities of 12,000 Btuh, 18,000 Btuh, and 24,000 Btuh ((equivalent to 1, 1.5, and 2 refrigeration tons). Some of the units are still manufactured with HCFC-22 and some with HFC refrigerants which prompted building prototypes for alternatives to HCFC-22 as well as R-410A. .

Manufacturers also build what is termed as Central or Packaged units. Several manufacturers produce these units in the 10 Tons (120,000 Btuh or 35 kW) capacity but also in larger capacities of 20 and 25 tons. A 10 Ton Central unit was added to the categories to be tested. Only HCFC-22 alternatives were used for this category. The Central category does not include a prototype with HC-290 because of the relatively high amount of charge needed. The stakeholders preferred to wait for the result of further risk assessment work being done in the region.

One of the technology stakeholders (Danfoss) suggested building at least one prototype with condenser micro-channel heat exchangers (HX). Micro-channel HX technology is proven for conventional refrigerants and uses less refrigerant charge. One of the OEMs took up the challenge to build an extra Central unit with micro-channel HX.

Table 3 below shows the matrix of the prototypes that were agreed upon. Green highlighted areas are for units built, while red denotes the unused portion of the central units as mentioned above.

Table 3 Matrix of prototypes showing refrigerants selected for each equipment category

		Split system (mini-split)			Central 120,000 Btuh	
	Replacement for	12,000 Btuh	18,000 Btuh	24,000 Btuh	Std. coil	micro channel
HC-290	HCFC-22					
HFC-32	R-410A					
R-457C (Arkema ARM-20a)	HCFC-22					
R-459A (Arkema ARM -71a)	R-410A					
R-454C (Chemours DR-3)	HCFC-22					
R-454B (Chemours DR-5A)	R-410A					
R-444B (Honeywell L-20)	HCFC-22					
R-447A (Honeywell L-41)	R-410A					
HCFC-22 base						
R-410A						

OEMs were asked to supply from their standard manufacturing line units with baseline refrigerants equivalent in capacity to each prototypes in order to compare units built by the same OEM.

The test results of the central units are not covered in this report.

1.5. Stakeholders:

The project stakeholders:

The Ministry of Environmental Affairs. The following entities at the ministry provided overall supervision and monitoring of the project**:**

- **The Egyptian Environmental Affairs Agency (EEAA):** The Chief Executive Director of EEAA has direct responsibility for the supervision of the activities of the National Ozone Unit.
- **The National Ozone Unit (NOU):** The NOU as an integral part of the Ministry for Environmental Affairs may draw on the legal and technical expertise and resources of the Ministry to undertake its responsibilities. It cooperates with other relevant divisions and field offices of the Ministry and EEAA for carrying out its activities**.**

The Manufacturers (OEMs): Local manufacturers cooperated with Technology Providers to build and test agreed upon prototypes. Eight OEMs participated in the project, listed in alphabetical order:

- **DCM: (Delta Construction Manufacturing):** a manufacturer of central air conditioning equipment;
- **EGAT (Egyptian German Air Treatment Company):** a manufacturer of ducted split and central air conditioners along with airside equipment for commercial and industrial air conditioning;
- **Elaraby Company for Air Conditioning:** a manufacturer of air conditioners and home appliances, Elaraby partners with Sharp on technology for air conditioning equipment;
- **FRESH Electric for Home Appliances:** a manufacturer of air conditioners and home appliances;
- **Miraco Carrier:** a manufacturer of residential and commercial air conditioning equipment. Miraco also partners with Midea;
- **Power Egypt:** a manufacturer of small and central commercial & residential air conditioning equipment;
- **Unionaire:** a manufacturer of air conditioners and home appliances;
- **Volta Egypt:** a manufacturer of central air conditioning equipment.

Note on Confidentiality: To ensure the confidentiality of results, OEMs were given random designations from A to H and the results were reported under this designation.

The Technology Providers: Provide sample raw materials (refrigerants, compressors, and micro-channel coils) in addition to technical support when needed;

- **Chemours (ex-DuPont):** Provided refrigerants R-454C and R-454B;
- **Daikin:** Provided refrigerant HFC-32;
- **Danfoss:** provided micro-channel HX condenser coils for one central unit;
- **Emerson:** provided compressors for some split systems and all central units;
- **GMCC:** Provided compressors for some of the split systems;
- **Hitachi Highly:** provided compressors for some of the split systems;
- **Honeywell:** provided refrigerants R-444B and R-447A.

1.6. Methodology

The local manufacturers volunteered to build a certain number of prototypes each and provided standard units from their production line running on the baseline refrigerants against which the particular prototypes were compared. Baseline units are with either HCFC-22 or R-410A refrigerants.

The assignment of categories and refrigerants to each of the OEMs was based on a questionnaire in which they listed their preferences and their capabilities to take on the work. The questionnaire can be found in Annex 2. Coordination meetings were held with the OEMs in which some of the technology providers were also present. These meetings and the subsequent contacts with the OEMs facilitated the logistics of shipping both the compressors and the refrigerants to the different OEMs

The prototypes were built with the following constraints:

- Using dedicated compressors provided by the project for each type of alternative refrigerant;
- Using the same unit overall dimensions as the base unit, i.e. the heat exchangers could not be oversized in order to compare with the baseline unit. The overall dimensions of the unit were hence kept the same;
- Prototypes needed to meet the MEPS as set out by the Egyptian Organization for Standards EOS 3795:2013 equivalent to ISO 5151 at T_1 conditions as a minimum.
- OEMs provided throttling devices (capillary, flow controls…) according to guidance from refrigerant manufacturers for optimization.

EOS 3795:2013 stipulates for split units less than 65,000 Btuh capacity an EER of 9.5 equivalent to a COP of 2.78 W/W at T_1 conditions.

The OEMs optimized the prototypes by changing the refrigerant charge and the expansion devices. No special coil designs were made for this project except for the micro-channel HX coils used on the central unit. The constraint of keeping the same coils has an effect on the optimization of the prototype; however, since the purpose of the tests is to compare to a baseline unit using HCFC-22 or R-410A refrigerants, this constraint was accepted by the stakeholders.

The Table below shows the number and type of prototype built by each of the OEMs

Table 4 Prototypes and type of refrigerant built by the different OEMs

Category	**12 000 Btuh**		**18 000 Btuh**		**24 000 Btuh**	
OEM	**HCFC-22 Alternatives**	**R-410 A Alternatives**	**HCFC-22 Alternatives**	**R-410 A Alternatives**	**HCFC-22 Alternatives**	**R-410 A Alternatives**
A	R-444B	R-447A	R-290	HFC-32 and R-454B	-	-
B	R-454C	HFC-32	R-457A	-	R-444B	-
C	R-290 and R-457C	-	R-457A	R-459A	-	HFC-32 and R-454B
D	-	-	R-444B	-	R-457C	-
E	R-454C	R-454B	-	-	-	-

1.7. Testing Parameters and Facilities

EGYPRA testing protocol followed the following testing conditions:

Table 5 Testing conditions for outdoor and indoor dry and wet bulb temperatures

	T_1	T_3	T_{High}	$T_{Extreme}$
Outdoor °C db/wb	35/24	46/24	50/24	55/24
Indoor °C db/wb	27/19	29/19	32/23	32/23

The indoor conditions at T_{High} and $T_{Extreme}$ are not the same as those at T_3 conditions, they were chosen in agreement with the OEMs and are in conformity with ISO 5151 which is followed in Egypt. These indoor conditions are also not the same as in the other testing projects shown in Annex 4. Since the objective of EGYPRA is to compare the performance of AC units with medium and low-GWP alternative refrigerants against units with baseline refrigerants, this comparison remains true as long as the conditions of testing are consistent.

EGYPRA testing facilities: The project managers wanted to use one independent testing lab for testing all units in order to provide a continuity and similitude of testing. The government's accredited lab was contacted for that purpose; however, the lab did not have the capability of testing flammable refrigerants. Efforts at upgrading the lab capabilities could not be finished in time for the project timeline and the project adapted the strategy of witness testing at the manufacturers' testing facilities. The Technical Consultant witnessed all the tests and verified the results. A brief description of the OEM testing facilities can be found in Annex 3.

Testing Methodology:

Testing of the units followed the Egyptian standard EOS 4814, non-ducted AC & HP testing and rating performance. The standard is derived from ISO-5151 and is followed by all manufacturers. The standard stipulates that,

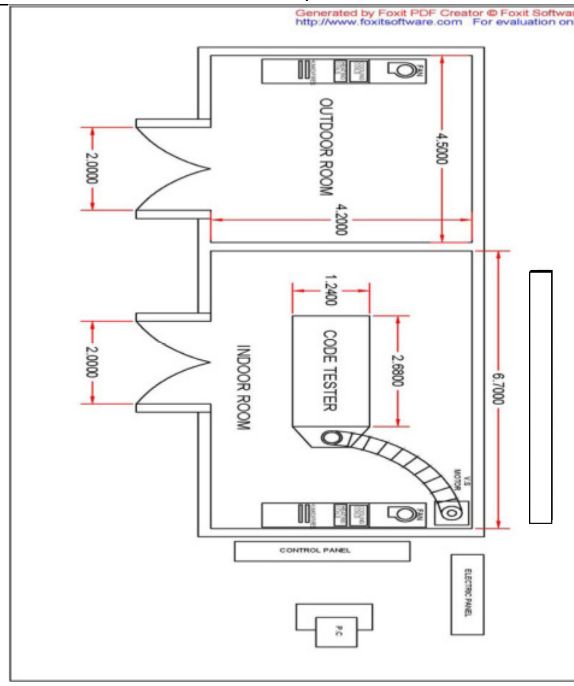
> *"4.1.1.2.5 Machines manufactured for use in more than one of the climatic conditions as T_3, T_2 and T_1 shall be rated and recorded at each of the conditions for which the unit was designed."*

The Egyptian standards do not stipulate testing at temperatures higher than T_3. The T_{High} and $T_{Extreme}$ conditions were derived from ISO 5151 with the agreement of the OEMs.

The tests were witnessed by the Technical Consultant. Re-testing the units was permitted when the results were inconsistent or did not meet the minimum EER stipulated in EOS 3795. The Technical Consultant advised the OEMs on possible remedies and helped them in the determination of the charge and the expansion device setting to achieve better results.

Testing procedure

Table below describes the testing procedure applied by all OEMs

No.	Item	Description
1	Testing lab infrastructure: • Testing chamber description Note: (Typical testing laboratory's testing chambers schematic diagram shown. Dimensions and arrangement of equipment are for indicative purposes only.)	 I. Laboratory is used for measuring capacities less than 1, 1, 1.5, 2 TR. Laboratory of the psychometric type where the air conditioner cooling capacity, heating capacity and unit efficiency (EER, COP) can be measured accurately. II. Other parameters such as unit working pressure, superheat, subcooling and state point's temperature of the refrigeration cycle could also be measured. III. Laboratory consists of two thermally insulated chambers (indoor and outdoor chambers). Both chamber's temperature and humidity can be controlled precisely to achieve the required state point (as per standards) using AC units, humidifiers and electric heater. IV. The accuracy of temperature control for dry and wet bulb temperatures to be 0.01 ^{o}C or better. V. The indoor room to have a thermal insulated code tester to collect all outlet air from the air conditioner, measuring its dry bulb and wet bulb temperatures and air volume
	• Parameters measured & instrumentation used	• All temperature sensors for inlet and leaving air in indoor room as well as outdoor room air temperatures are to be measured. • Surface temperatures to be measured by sensors - accuracy 0.1 ^{o}C or better-for both indoor and outdoor chambers. A minimum of 15 measuring points to be used for each room at various locations on the air conditioner. • All data gathered during an experiment to be read by a computer through a specialized program with multi channels data acquisition to get the required data in a live format fashion. • Factory supplied control panel located outside the chambers space to have all necessary control switches to

		operate the laboratory and set the required conditions with power meters for single phase and 3 phase and all electrical data for tested units. Data to be measured and transferred to computer system.
2	Standards to be used:	All tests for cooling and heating performance to be performed according to the following standards: • EOS 4814 non-ducted AC & HP testing and rating performance • ASHRAE testing standards • ISO 5151 for non-ducted air conditioners • ISO 13253 for ducted type split • EOS 3795-1/2016 • EOS 3795-2/2017
3	Description of the testing procedures: • Description of testing method	• Psychometric testing method is used as per ISO 5151-2017 annex C, G. Air flow rates are to be measured through nozzles for both entering and leaving dry and wet bulb temperatures.
	• Method of selection of capillary tube and choosing refrigerant charge	• Optimum selection of capillary size, length, number and refrigerant charge to achieve good matching and improved performance for the unit according to the following: i) Select from preliminary capillary chart size, number and length of the required capillary to match the specified load. ii) Accumulated experience plays an important role in determining the preliminary refrigerant charge. iii) Testing the unit based on pervious selections give an indication for system optimization including increasing or decreasing the charge and/or the size of the capillary. iv) System pressure, superheat, subcooling, power consumption, cooling capacity and refrigerant temperature at various points of the cycle give a strong indication on how the matching is proceeding.
	• Achieving steady state for outdoor and indoor conditions (description, time needed…)	• 2 hours' time are needed as a minimum to achieve the steady state condition for testing cooling capacity of the unit as well as EER or COP.
4	Calculating EER and capacity: • How the EER is calculated measurements used and formula	EER= cooling capacity/ total power consumed by the system in Btuh/W or equivalent.
	• How the capacity was calculated measurements used and formula	As per ISO 5151 see equations in annex C
5	The air psychometric process: • The cycle on psychometric chart	• Test result to provide all required information to draw the cycle on Psychometric chart: ○ E_{DB},L_{DB},E_{WB},L_{DB} (E=Enthalpy)
	• Explanation of state points at T_1, T_3, T_h and T_{ext}	• Test result to provide all required data to draw and change, when needed, the cycle on the PH diagram: ○ High pressure. ○ Compressor discharge temp. ○ Subcooling amount in condenser. ○ Low pressure. ○ Compressor suction temperature. ○ Superheat amount in evaporator for all required tests T_1, T_3, T_h and T_{ext} .

Chapter 2

2. Results

The results of the various tests were combined under two major headings: results of alternatives to HCFC-22 and results of alternatives to R-410A. The presentation or comparison of results across the two major headings does not lead to tangible conclusions while the separation of the discussion under the two baseline refrigerants leads to a better understanding of the information.

The casual reading of the results may establish confusion, even among specialists, in relation to the increase in capacity at T_{High} compared to T_3. This result is not witnessed in other similar research projects; however, by understanding the impact of changing the dry bulb and wet bulb indoor testing conditions i.e. T_{high} (outdoor 50/24 ^oC, indoor 32/24 ^oC) compared to T_3 (outdoor 46/24 ^oC, indoor 29/19 ^oC), the results can be justified using the modeling approach explained below. The additional exercise to review and validate all results is the reason for the unplanned delay in concluding the project report.

Modeling Using ORNL Heat Pump Design Model

Since the measurements provided by the labs were somehow limited, it was difficult to explain the hypothesis for the increase in performance under T_{High} conditions. As such, a full-scale modeling using the ORNL Flexible Heat Pump Model was performed on a sample packaged air conditioning system and the indoor and outdoor conditions were changed according to the EGYPRA conditions: T_1, T_3, T_{Hot}, and T_{High}. Table 5 above provides a summary of the indoor and ambient conditions for the four simulations along with the capacity ratio (capacity/capacity at T_1), compressor mass flow rate, compressor power, sensible heat ratio (SHR), and evaporator overall area integral heat transfer for the vapor (UA_vap) and the 2 phase (UA_2-ph) portions respectively.

The T_{Hot} condition was selected to simulate the same ambient conditions as that tested by the OEMs but with the same indoor conditions as T_1 and T_3. The results for this simulation follows the simple intuition that as the ambient temperature increases, the performance degrades at a rough order of magnitude of 1% point per 1°C of outdoor temperature increase. However, when examining the performance of the T_{High} condition; we notice a sudden increase in capacity – coupled with an increase in refrigerant mass flow rate, and reduction in SHR. The simulation results show that for T_1, T_3 and T_{Hot} conditions, the suction saturation temperature change was less than 1°C, while when the indoor conditions were changed to the T_{High} condition, the suction saturation temperature changed by more than 4°C. This has an impact on the compression ratio, compressor suction density, and compressor performance (volumetric and isentropic efficiencies). Furthermore, the higher humidity associated with the T_{High} condition induces the evaporator coil to become wetter and as such results in higher airside performance and higher SHR.

Table 6: Conditions and relevant results for the rooftop unit simulated using the ORNL Flexible HPDM simulation tool

Condition	**EDB**	**EWB**	**Ambient**	**Capacity/Capacity at T1**	**Compressor mass flow rate**	**Compressor Power**	**SHR**	**Evaporator vapor UA**	**Evaporator 2-ph UA**
	°C	°C	°C	%	g/s	W	%	W/K	W/K
T1	29	19	35	100%	379.8	14,074.9	88%	5.6	265.7
T3	29	19	46	89%	383.7	16,952.9	93%	6.7	265.1
T_{Hot}	29	19	50	86%	384.6	18,077.2	95%	6.7	265.2
T_{High}	32	23	50	94%	433.9	18,693.8	78%	9.4	261.3

Hypothesis summary

When the indoor dry bulb and wet bulb temperatures are increased from the T_3 conditions to the T_{High} conditions; the sensible heat ratio of the AC system is reduced, and a large portion of the evaporator is wetted by the condensate. This results in heat transfer enhancement due to reduced free flow area and increased surface velocity and the concurrence of heat and mass transfer at the tubes and fin surfaces. From further analysis provided by the detailed study from OEM C; the evaporator log mean temperature difference is also increased due to the increased air inlet temperature. Hence on the air side, both the increase in overall heat transfer coefficient along with the increased evaporator LMTD and increased latent capacity contribute directly to the increased heat capacity between T_3 and T_3 with elevated indoor conditions (subsequently also the increased capacity at the T_{High} conditions).

At the refrigerant side, when the indoor conditions are changed from the T_3 to the T_{High} conditions – the compressor pressure ratio is reduced while the compressor inlet density is increased. The refrigerant flow rate also increases which further justifies the increased cooling capacity from the refrigerant side analysis.

2.1 Presentation and Analysis of Results

The analysis of the results is presented in table form. The complete results and comparative bar charts are found in Annex 1.

The Results for capacity in Btuh and energy efficiency in EER (energy efficiency ratio in MBH output/ kW input) are given for the four testing temperatures. The tables show the test results and the percentage increase or decrease in capacity and EER compared to the baseline unit. As a reminder, each OEM was asked to test a baseline unit from their own standard production for each prototype built in order to compare with the results.

The analysis uses shades of color to denote the comparison level to the baseline unit as follows:

No shading	Performance is same as base unit – for capacity and EER
Green	**Increase** in EER or cooling capacity over baseline unit
Yellow	**Decrease** in EER or cooling capacity by **- 0.01 % to - 5 %**
Orange	**Decrease** in EER or cooling capacity from **-5 % to - 10 %**
Red	**Decrease** in EER or cooling capacity over **-10 %**

The results are then plotted on a scattered chart for the ratio of capacity of the prototype to that of the baseline unit vs. the EER ratio at the four testing temperatures. The baseline unit performance is denoted by the two red dotted lines at a ratio of one for both capacity and EER.

The analysis is presented for the alternatives of HCFC-22 and R-410A separately. Some results for inconclusive tests mentioned in the Annex were not used in the analysis.

2.1.1. Analysis of Capacity and EER Performance for HCFC-22 Alternatives

The tables in this section are for alternatives to HCFC-22 for the three categories of mini-split units: 12,000 Btuh, 18,000 Btuh, and 24,000 Btuh.

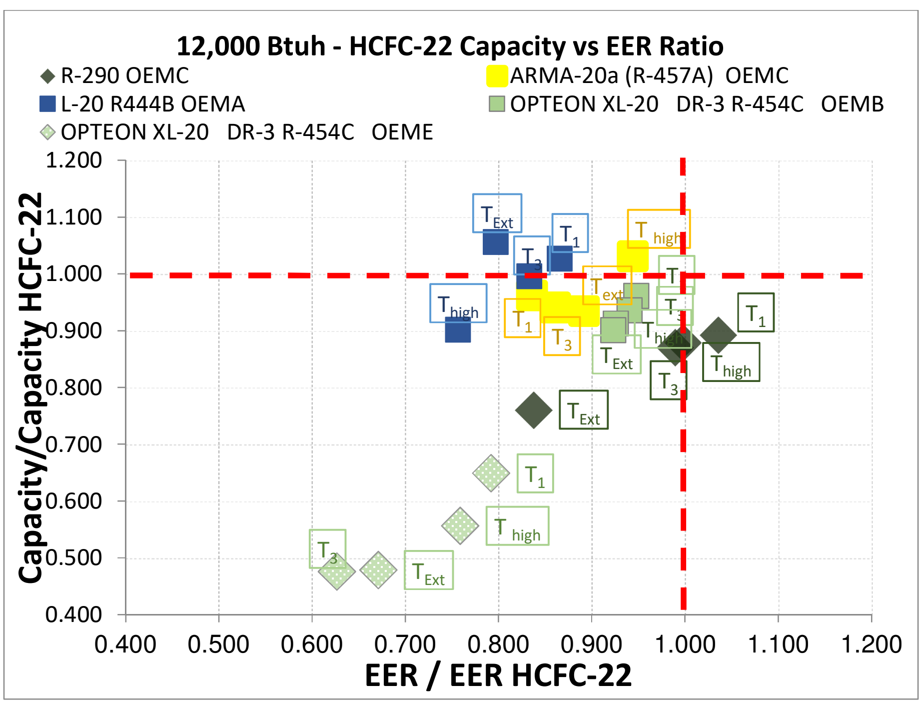
Results for the 12,000 Btuh category

Table 7 Comparison of HCFC-22 alternatives for 12,000 Btuh split units

HFCF-22 12,000 Btuh	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
	Capacity in Btuh				EER			
Base Units								
R-22(OEM C)	11,452	9,960	10,560	10,181	10.0	7.25	6.98	6.23
R-22(OEM B)	11,410	9,988	10,900	10,035	8.41	6.38	6.33	5.47
R-22(OEM A)	11,479	9,699	11,353	8,407	9.74	6.88	7.31	5.61
Prototypes								
HC-290 (OEMC)	10,219 (-10.77%)	8,677 (-12.88%)	9,289 (-12.04%)	7,747 (-23.91%)	10.36 (+3.53%)	7.17 (-1.1%)	6.96 (-0.23%)	5.22 (-16.2%)
R-457A (OEM C)	11,023 (-3.75%)	9,376 (-5.86%)	10,892 (+3.14%)	9,517 (-6.52%)	8.36 (-16.44%)	6.24 (-13.93%)	6.58 (-5.63%)	5.56 (-10.83%)
R-454 C (OEM B)	10,968 (-3.87%)	9,349 (-6.40%)	9,946 (-8.75%)	9,042 (-9.90%)	7.97 (-5.23%)	6.00 (-5.96%)	5.86 (-7.42%)	5.05 (-7.68%)
R-444 B (OEM A)	11,790 (+2.71%)	9,661 (-0.39%)	10,241 (-9.79%)	8,881 (+5.64%)	8.43 (-13.45%)	5.73 (-16.72%)	5.53 (-24.35%)	4.47 (-20.32%)

The table shows that for HC-290, the capacity of the prototype at all four temperatures is less than that of HCFC-22 baseline, while the EER is higher at T_1 and within 1% at T_3 and $T_{High.}$ The results for R-457A and R-454C show results for capacity up to 10% less than the baseline with R-457A showing a better capacity at Thigh which is not the case for R-454C. For R-444B, capacity is better than the baseline at both T_1 and $T_{Extreme}$ but 10% worse at T_{High} which cannot be explained. EER for R-444B is more than 10% worse than the baseline. Plotted on a scattered chart as follows

Figure 1 Capacity vs. EER ratio for HCFC-22 alternatives in 12,000 Btuh split units



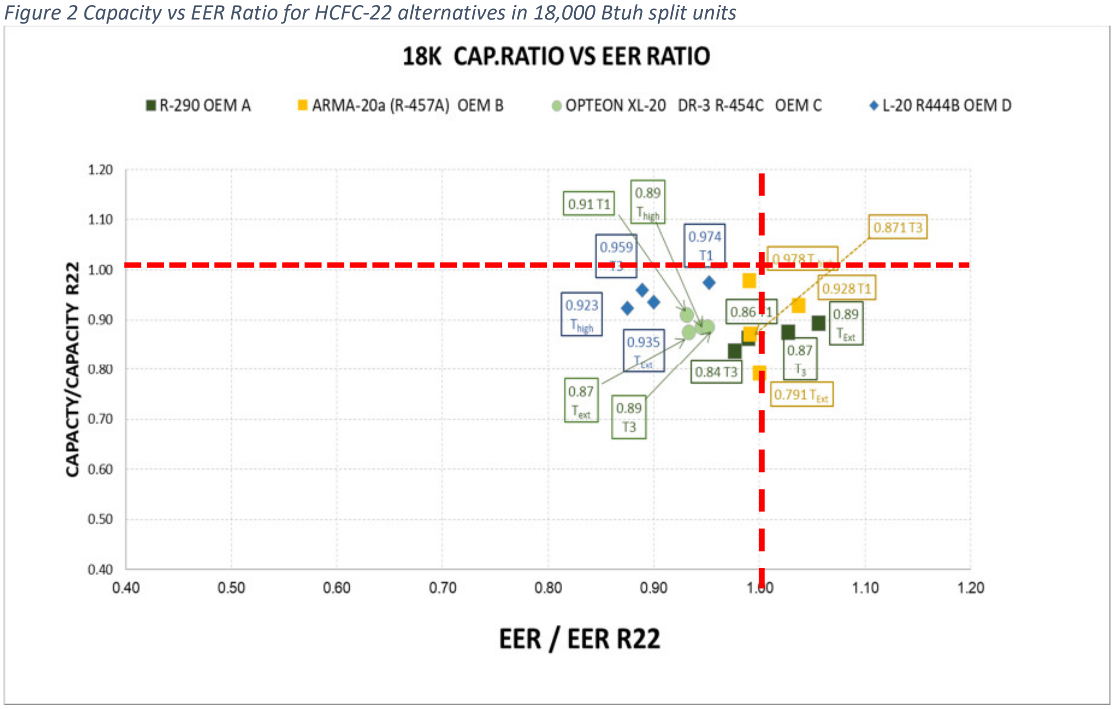
Results for 18,000 Btuh Splits

Table 8 Comparison of HCFC-22 alternatives for 18,000 Btuh split units

18,000 Btuh	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline Units								
HCFC-22								
OEM A	18,659	16,799	17,543	15,046	9.41	7.20	6.98	5.55
OEM B	16,433	14,545	13,718	15,350	8.93	6.65	6.37	5.33
OEM C	18,160	16,182	17,632	16,292	10.00	7.37	7.37	6.45
OEM D	17,548	16,422	14,624	13,948	10.50	8.75	7.22	6.00
Prototypes								
R-290 (OEM A)	*16,111 (-13.66%)*	*14,067 (-16.26%)*	*15,343 (-12.54%)*	*13,442 (-10.66%)*	9.31 (-1.06%)	7.090 (-2.34%)	7.170 (+2.72%)	5.860 (+5.59%)
R-444 B (OEM D)	*17,098 (-2.56%)*	*15,746 (-4.12%)*	*13,498 (-7.70%)*	*13,047 (-6.46%)*	10.00 (-4.76%)	7.78 (-11.01%)	6.32 (-12.47%)	5.40 (-10.00%)
R-454 C (OEM C)	*16,510 (-9.09%)*	*14,327 (-11.46%)*	*15,619 (-11.42%)*	*14,250 (-12.53%)*	9.31 (-6.88%)	6.97 (-5.43%)	7.01 (-4.88%)	6.02 (-6.67%)
R-457 A (OEM B)	*15,257 (-7.16%)*	*12,672 (-12.88%)*	*13,418 (-2.19%)*	*12,149 (-20.85%)*	9.26 (+3.70%)	6.59 (-0.90%)	6.31 (-0.94%)	5.33 (0.00%)

The results for HC-290 for capacity are consistent with the results of the 12,000 Btuh category, while the EER shows better results than the baseline at T_{High} and $T_{Extreme.}$ The results for R-457C capacity compared to the 12,000 Btuh category show a further degradation compared to the baseline for the 18,000 Btuh category, while the EER results at the four temperatures are better than the 12,00 Btuh category. The same can be said about R-454C, while R-444B has comparable results with the 12,000 Btuh category with a variation with temperature. The results of this category show higher values for both capacity and EER for T High results compared to T3 in line with the discussion at the beginning of this chapter.

Figure 2 Capacity vs EER Ratio for HCFC-22 alternatives in 18,000 Btuh split units



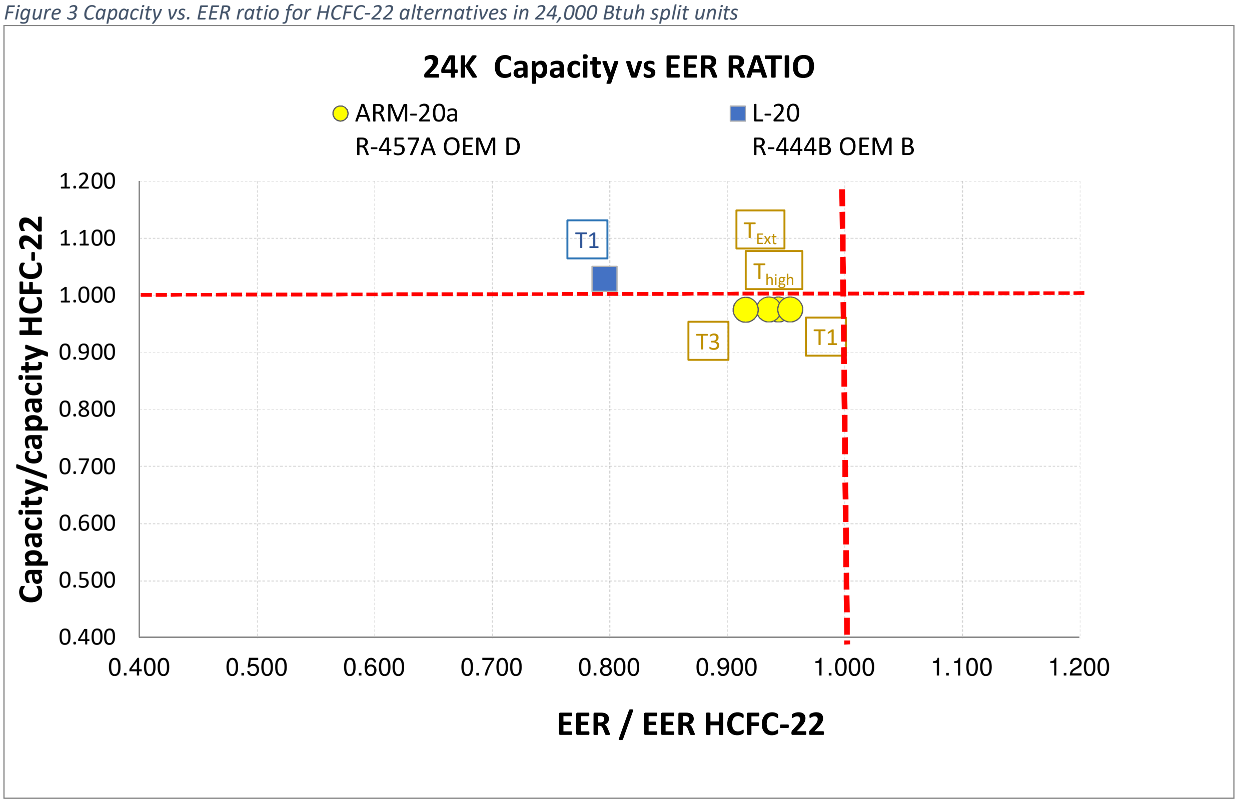
Results for 24,000 splits

Table 9 Comparison of HCFC-22 alternatives for 24,000 Btuh split units

24,000 Btuh	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
HCFC-22 OEM B OEM D	 22,782 22,318	 N/A 21,202	 N/A 20,144	 N/A 19,148	 9.27 9.30	 N/A 7.32	 N/A 6.10	 N/A 5.73
Prototypes								
R-444 B (OEM B)	23,436 (+2.87%)	N/A	N/A	N/A	7.38 (-20.39%)	N/A	N/A	N/A
R-457 A (OEM D)	21,758 (-2.51%)	20,670 (-2.51%)	19,636 (-2.52%)	18,657 (-2.56%)	8.78 (-5.59%)	6.85 (-6.42%)	5.82 (-4.59%)	5.25 (-8.38%)

Unfortunately, the data for R-444B at temperatures other than T_1 were not available. Data for R-457A as a percentage of the baseline by the same OEM show a better trend than for the other two categories; however, in absolute terms the EER of the baseline of the 24,000 Btuh category is lower than the other two categories which explains the higher percentage.

Figure 3 Capacity vs. EER ratio for HCFC-22 alternatives in 24,000 Btuh split units



Note that the results for the capacity for R-457A at the four temperatures are similar and hence the yellow circle label points seem almost concentric.

2.1.2. Analysis of Capacity and EER Performance for R-410A Alternatives

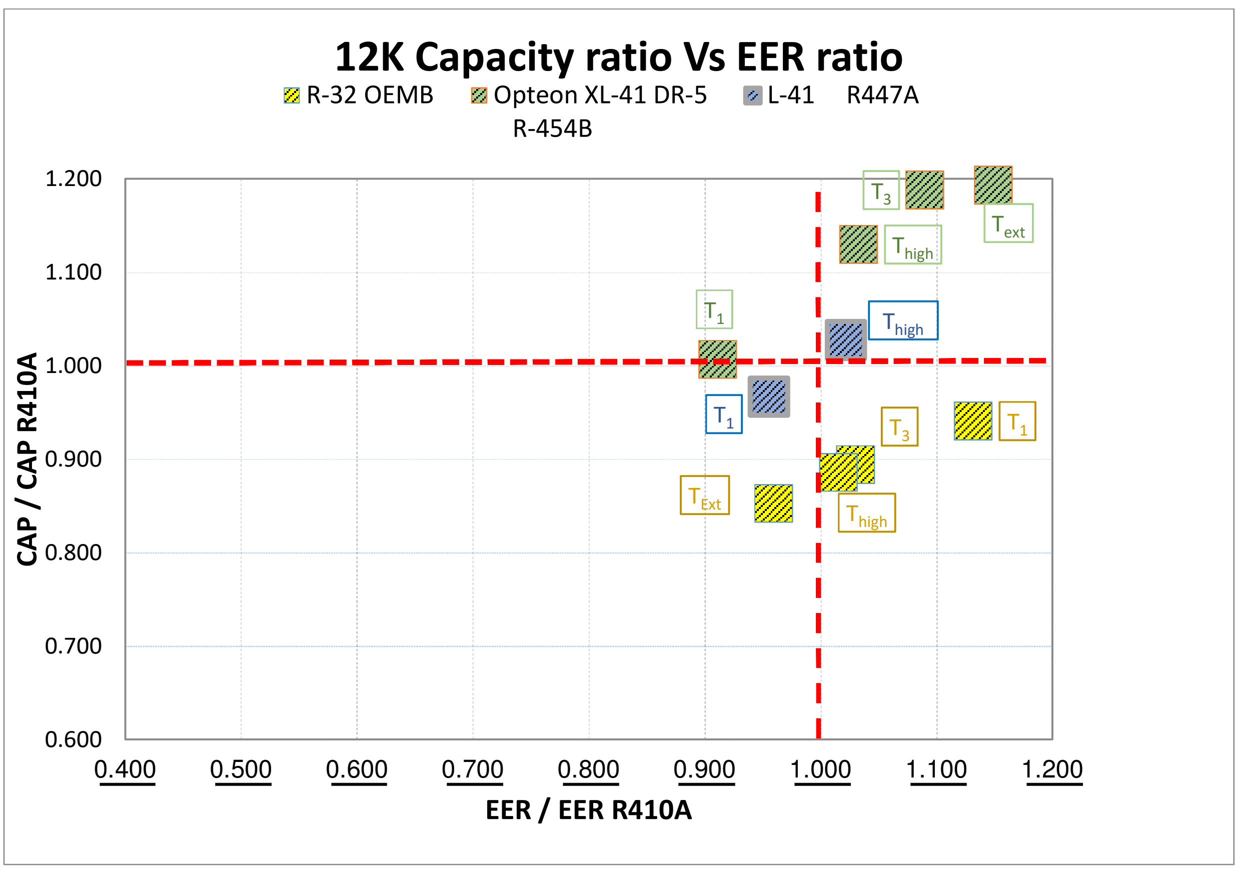
Results for 12,000 Btuh splits

Table 10 Comparison of R-410A alternatives for 12,000 Btuh split units

12,000	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
R-410A								
OEM A	10,307	N\A	8,313	N\A	8.77	N\A	5.43	N\A
OEM B	12,068	10,343	11,089	9,968	10.17	7.31	7.15	5.93
OEM E	11,905	9,369	10,848	9,299	10.88	7.29	7.42	5.89
Prototype								
HFC-32 (OEM B)	11355 (-5.91%)	9,249 (-10.58%)	9,822 (-11.435)	8,499 (-14.74%)	11.51 (+13.18%)	7.53 (+3.01%)	7.26 (+1.54%)	5.69 (-4.05%)
R-454B (OEM E)	11,987 (+0.69%)	11130 (+18.8%)	12,257 (+12.99%)	11,094 (+19.30%)	9.92 (-8.82%)	7.95 (+9.05%)	7.66 (+3.27%)	6.7 (+14.90%)
R-447A (OEM A)	9963 (-3.34%)	N\A N\A	8539 (+2.72%)	N\A N\A	8.38 (-4.45%)	N\A N\A	5.55 (+2.21%)	N\A N\A

The results for R-454B compared to the baseline is better except for the EER at T_1. Results for HFC-32 compared to the baseline show a higher performance for EER but lower for capacity.

Figure 4 Capacity vs EER ratio for R-410a alternatives in 12,000 Btuh split units



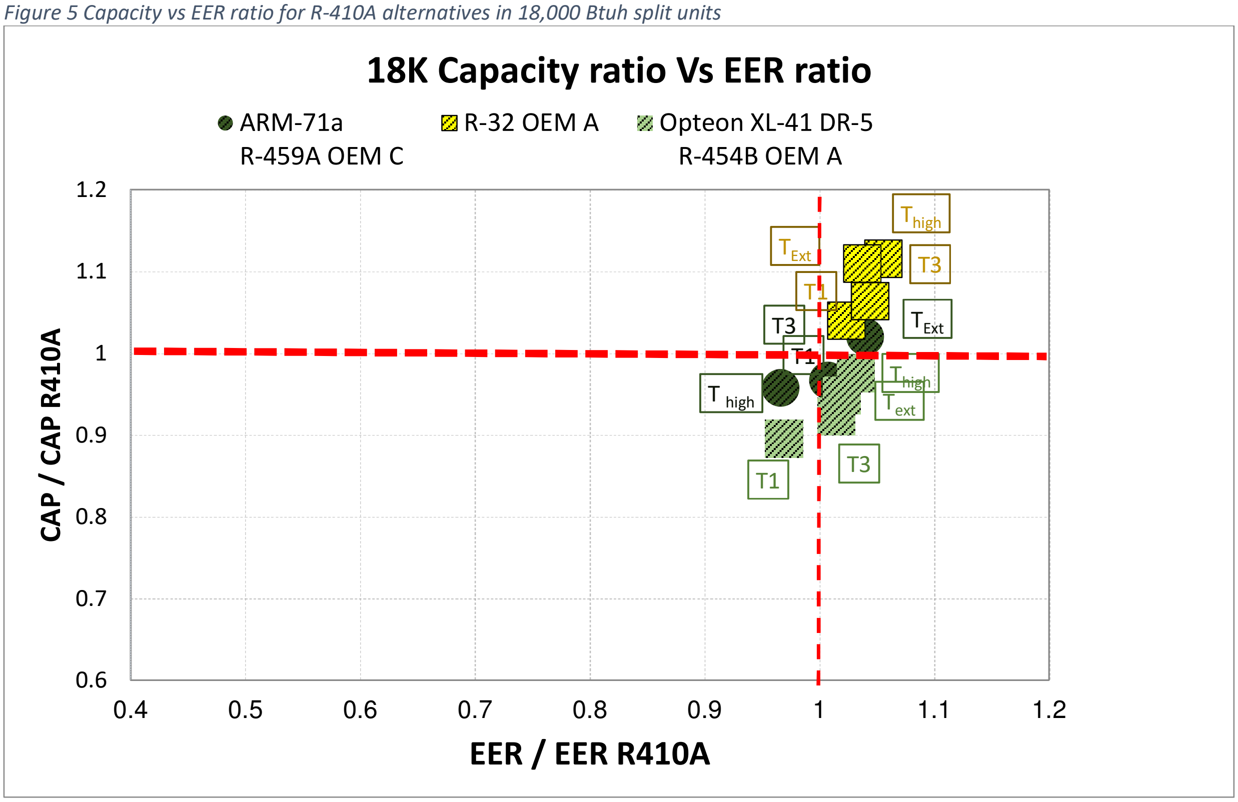
Results for 18,000 Btuh

Table 11 Comparison of R-410A alternatives for 18,000 Btuh split units

18,000	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
R- 410 A OEM A OEM C	 16,938 17,800	 14,337 14,924	 14,123 16,075	 12,441 13,746	 9.8 9.15	 6.8 6.50	 6.3 6.49	 5.1 5.12
Prototype								
R-459A (OEM C)	17,115 (-3.85%)	14,430 (-3.31%)	15,392 (-4.25%)	14,023 (+2.02%)	9.28 (+1.42%)	6.54 (+0.72%)	6.27 (-3.39%)	5.32 (+3.99%)
HFC-32 (OEM A)	17616 (+4.00%)	15,255 (+6.40%)	15,761 (+11.60%)	13,809 (+11.00%)	10.03 (+2.35%)	7.10 (+4.41%)	6.65 (+5.56%)	5.29 (+3.73%)
R-454B (OEM A)	15,167 (-10.46%)	13,229 (-7.73%)	13,782 (-2.41%)	11,800 (-5.15%)	9.5 (-3.06%)	6.90 (+1.47%)	6.50 (+3.17%)	5.20 (+1.96%)

The results for R-454B show a similar trend of higher values against the baseline to the 12,000 Btuh category for EER but lower for capacity. Results for HFC-32 are higher than the baseline for both capacity and EER, which is different from the 12,000 Btuh category.

Figure 5 Capacity vs EER ratio for R-410A alternatives in 18,000 Btuh split units



The plot shows that most of the results are on the positive side when compared to the baseline units for EER with some results for capacity showing lower values.

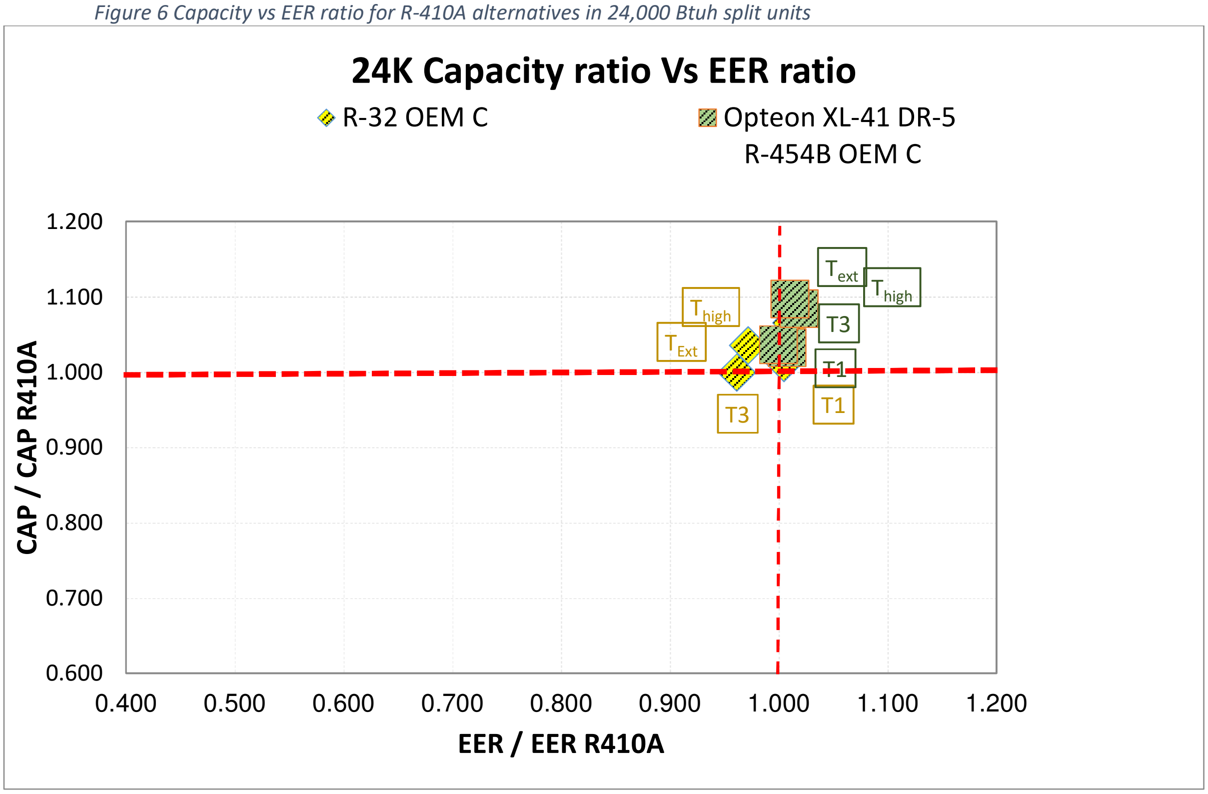
Results for 24,000 Btuh

Table 12 Comparison of R-410A alternatives for 24,000 Btuh split units

24,000	T_1	T_3	T_{High}	$T_{Extreme}$	T_1	T_3	T_{High}	$T_{Extreme}$
Refrigerant	Capacity				EER			
Baseline								
R- 410 A OEM C	23022	19531	20534	18379	10.57	7.518	7.376	6.161
Prototype								
HFC-32 (OEM C)	23310 (+1.25%)	19522 (-0.05%)	21876 (+6.54%)	19035 (+3.57%)	10.62 (-0.47%)	7.228 (-3.86%)	7.459 (+1.13%)	5.988 (-2.81%)
R-454B (OEM C)	23766 (+3.23%)	20241 (+3.64%)	22268 (+8.44%)	20160 (+9.69%)	10.653 (+0.79%)	7.516 (-0.03%)	7.515 (+1.88%)	6.224 (+1.02%)

Results are mostly positive for the two refrigerants tested at this category.

Figure 6 Capacity vs EER ratio for R-410A alternatives in 24,000 Btuh split units



Chapter 3

3. Analytical comparison & way forward

The purpose of the comparative analysis in this section is to determine the potential for improvement for the different alternative refrigerants at the different testing temperatures and for the three categories. Since we have three variables: refrigerants, testing temperatures, and category of equipment, the analysis fixed one of the variables and then calculated the percentage of incidence of cases where either the capacity or the EER are compared to the base unit falls in the five color categories defined earlier and repeated here for ease of reference.

No shading	Performance is same as base unit
Green	**Increase** in performance or cooling capacity over base unit
Yellow	**Decrease** in performance or cooling capacity by **- 0.01 % to - 5 %**
Orange	**Decrease** in performance or cooling capacity from **-5 % to - 10 %**
Red	**Decrease** in performance or cooling capacity over **-10 %**

As an example, consider the 12,000 Btuh category for all refrigerants and at all testing temperatures for the capacity comparison. We come up with the following table:

Table 13 Example of calculation of the comparative pie charts

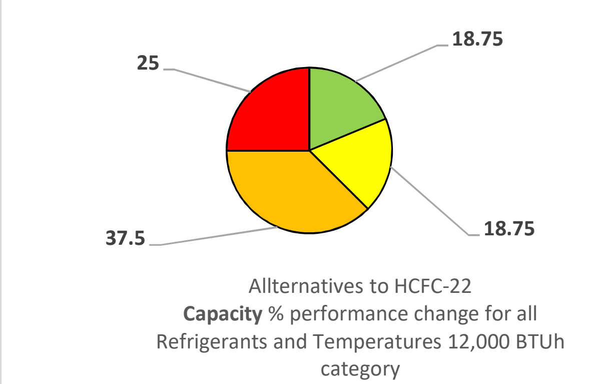
12,000 Btuh category	**Capacity**				
Refrigerant	T_1	T_3	T_{High}	$T_{Extreme}$	
R-290	10219	8677	9289	7747	
(OEM C)	(-10.77%)	(-12.88%)	(-12.04%)	(-23.91%)	
R-457 A	11023	9376	10892	9517	
(OEM C)	(-3.75%)	(-5.86%)	(+3.14%)	(-6.52%)	
R-454 C	10968	9349	9946	9042	
(OEM B)	(-3.87%)	(-6.40%)	(-8.75%)	(-9.90%)	
R-444 B	11790	9661	10241	8881	
(OEM A)	(+2.71%)	(-0.39%)	(-9.79%)	(+5.64%)	
	Calculation of incidence percentage				
	Green	Yellow	Orange	Red	No shading
Incidence: number of entries per color	**3**	**3**	**6**	**4**	**0**
Percentage of the 16 entries	**18.75%**	**18.75%**	**37.5%**	**25%**	**0%**

And the respective pie chart will look as in Figure 7 with the percentage of each incidence marked on the respective color. The pie chart is telling us that when we consider all the HCFC-22 refrigerant alternatives at all testing temperatures for the 12,000 category, there is

- 18.75% certainty that the result is better than the base,
- 18.75% that the result is up to 5% less compared to the base,
- 37.5% that the result between 5 and 10% less, and
- 25% that the results is over 10% less than the base.

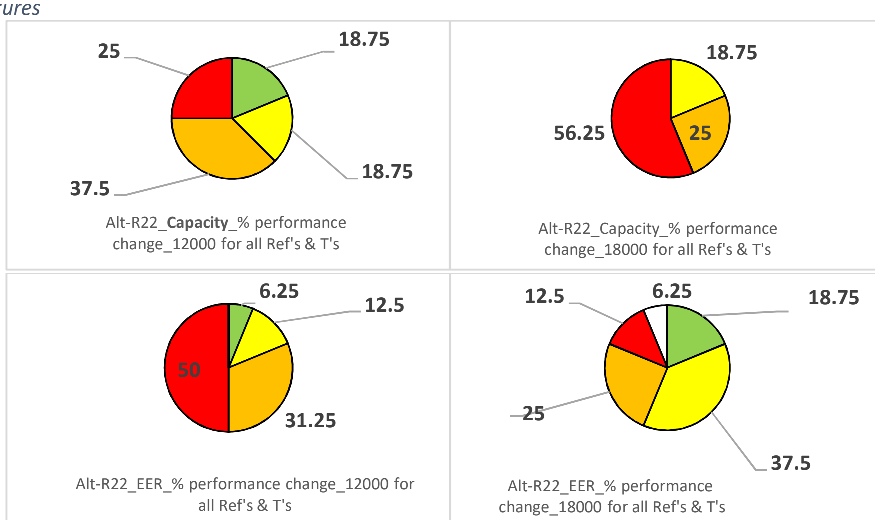
Similar comparative analysis will be made for the different cases for HCFC-22 alternatives and R-410A alternatives. The analysis clarifies the way forward and recommendations can be made for all the cases.

Figure 7 Example of pie chart for HCFC-22 alternatives in the 12,000 Btuh category



3.1. Capacity and EER behaviour of HCFC-22 Alternatives for each category across all refrigerants and testing temperatures

Figure 8 capacity and EER Performance of HCFC-22 alternatives for each category across all refrigerants and all testing temperatures



This analysis shows the following key observations:

For 12,000 Capacity:

- There is, certainly, potential to improve the capacity across 75% of refrigerants and at different testing temperatures
- On the EER side, the potential improvement drops down to 50%

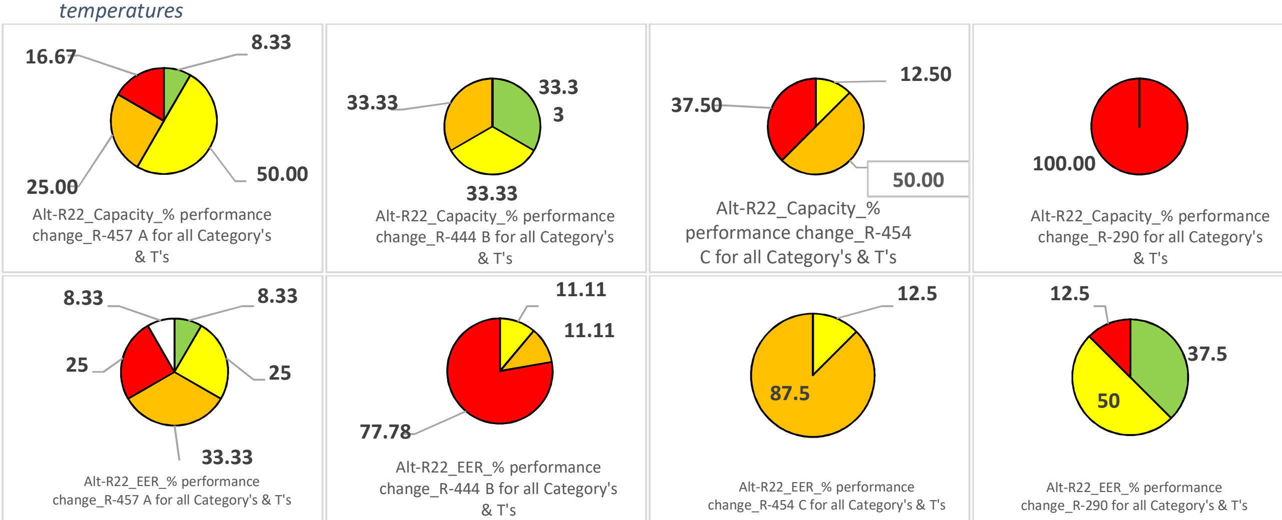
For 18,000 Capacity:

- There is less potentiality to improve capacity across all refrigerants and at different testing temperatures compared to the 12,000 category.
- However, opportunities to improve EER is much higher reaching over 85% across all refrigerants and at different testing temperatures

The 24,000 prototypes results were disregarded, since only one OEM tested one refrigerant across all test temperatures conditions. The other OEM tested another refrigerant at only one testing temperature condition. Therefore, a comparison of the results would be misleading.

3.2. Capacity and EER behaviour of HCFC-22 Alternatives for each refrigerant across all categories and testing temperatures

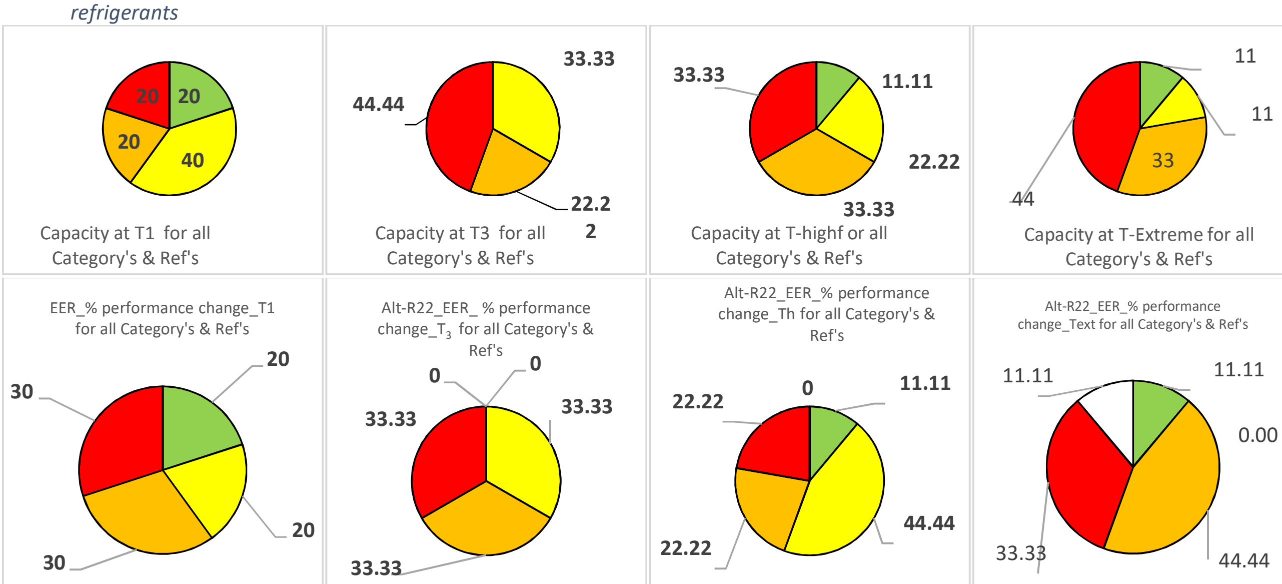
Figure 9 capacity and EER performance for HCFC-22 alternatives for each refrigerant across all categories and all testing temperatures



- Several alternatives to R-22 shows 60%, or above, chance for Capacity matching or improvement across all categories and at different testing temperatures.
- Most alternatives to R-22 shows 50%, or above, chance for EER improvement across all categories and at different testing temperatures.

3.3. Capacity and EER behaviour of HCFC-22 Alternatives for each testing temperature across all categories and refrigerants

Figure 10 Capacity and EER performance of HCFC-22 alternatives for each testing temperature across all categories and all refrigerants

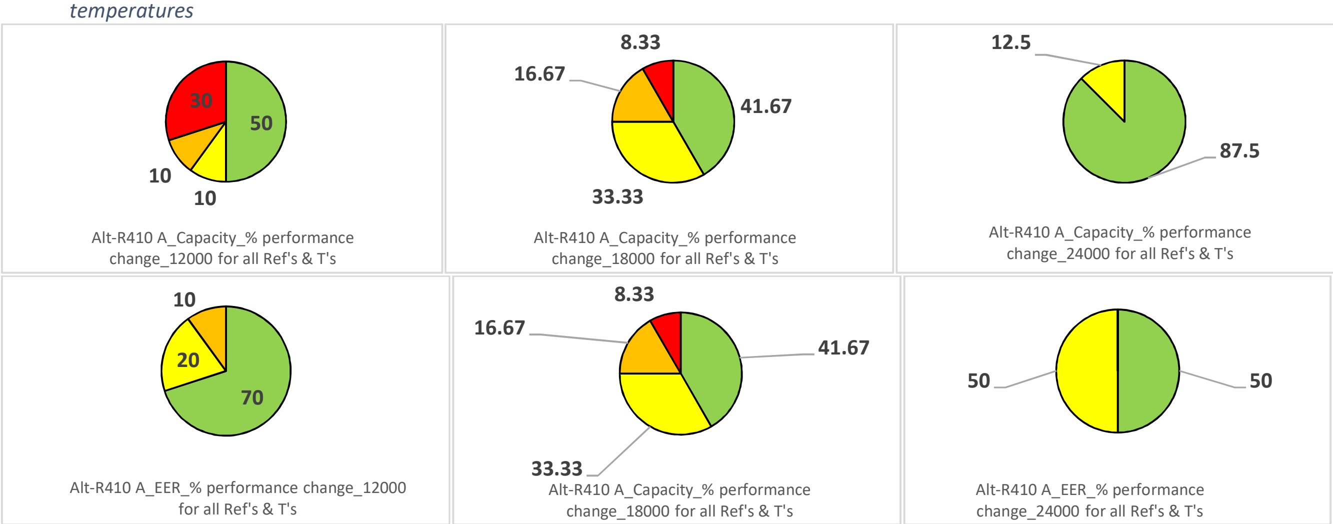


- As expected, moving from T1 to T3 testing temperatures, both capacity and EER deteriorate, at different levels, across all categories and refrigerants
- At T_{High}, the increased indoor wet bulb testing condition, as per EOS & ISO-5151, leads to better results for EER and capacity compared to T3

- Since $T_{Extreme}$ testing condition is similar to T_{High}, with regard to indoor wet bulb testing condition, both EER and capacity re-deteriorate.
- In general, there are candidates with potential improvement, more than 50%, across all categories at all high temperature testing conditions i.e. T_3, T_{high} & $T_{extreme}$.

3.4. Capacity and EER behaviour of R-410A Alternatives for each category across all refrigerants and testing temperatures

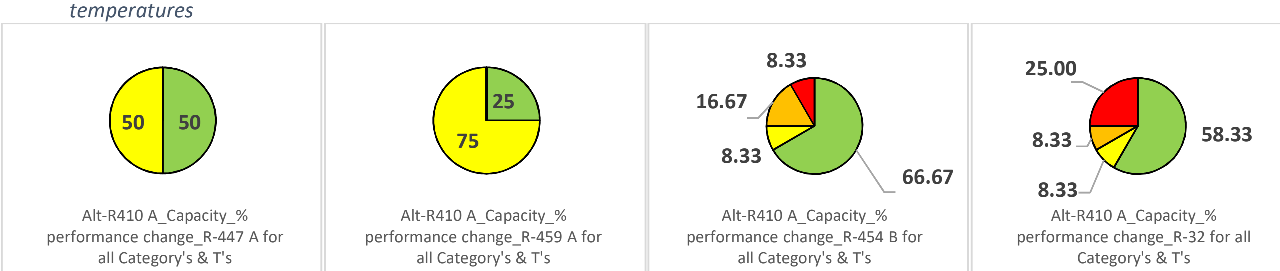
Figure 11 capacity and EER performance of R-410A alternatives for each category across all refrigerants and all testing temperatures

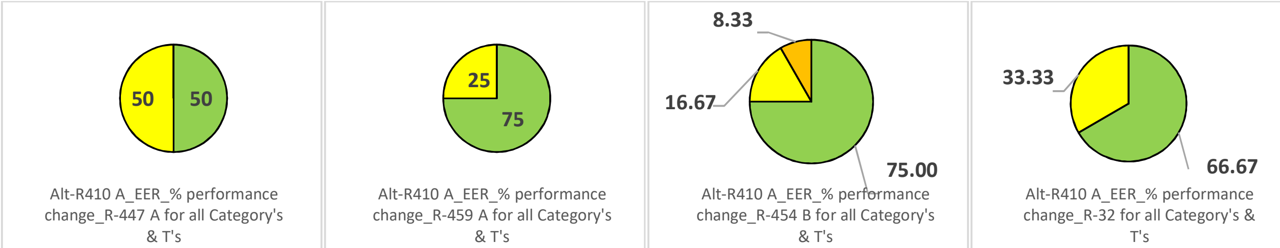


- Increase in capacity as category size increases, across all refrigerants and all testing temperate conditions.
- Capacity increases are from 50 % to 87.5 %.
- However, EER decreased as category size increases.
- EER improvement decreases from 70 % to 50 %.
- 18,000 showed capacity readings for all ranges similar to EER readings.
- 18,000 in the range (-0.1 % to - 5 %) readings for both capacity and EER were the same, 33.33 % instead of 10 % and 20 % in 12,000 size.
- The possibility of improving by optimization capacity and EER compared to R-410A are high

3.5. Capacity and EER behaviour of R-410A Alternatives for each refrigerant across all categories and testing temperatures

Figure 12 Capacity and EER performance of R-410A alternatives for each refrigerant across all categories and all testing temperatures

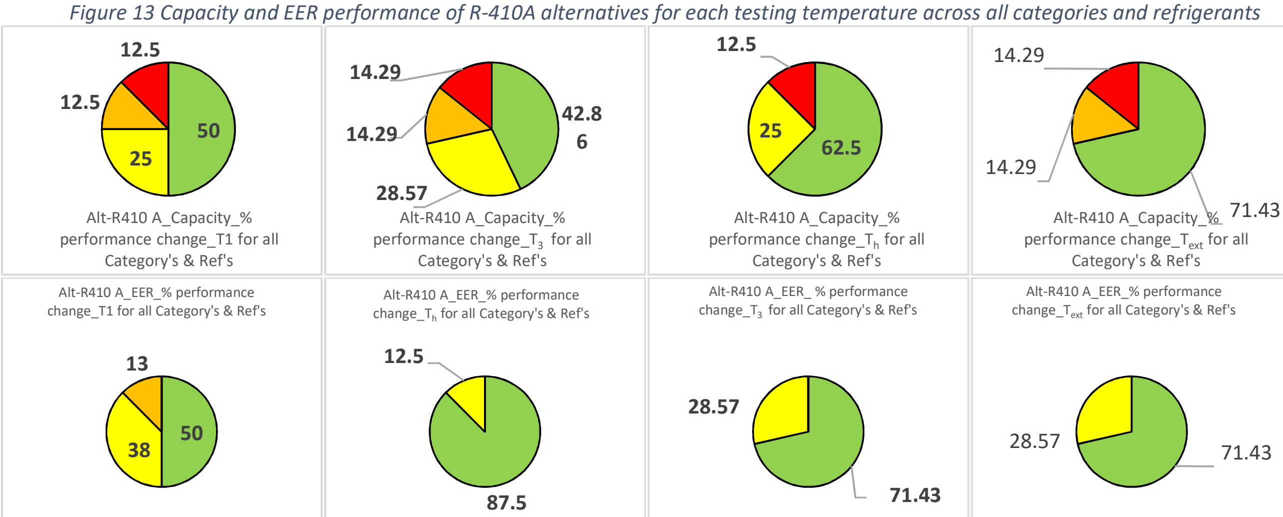




- All refrigerants showed improvement in capacity by 25% to 67 % and 50 % to 75 % in EER.
- One refrigerant was excluded from the comparison because of lack of data.
- All refrigerants have excellent chances of improvement in capacity and EER by optimization.

3.6. Capacity and EER behaviour of R-410A Alternatives for each temperature across all categories and refrigerants

Figure 13 Capacity and EER performance of R-410A alternatives for each testing temperature across all categories and refrigerants



- At T_1: 50 % of all test readings show better capacities than R-410 A for all refrigerants and categories and 50% better EER.
- At T_3 : 42.86 % decrease in capacity improvement to 42.86% and then improvement rose to 62.5% and 71.43 % at T_h and T_{ext}.
- At T_3 : 87.5 %improvement in EER. Improvement diminished slightly to 71.43 % for both T_h and T_{ext}.

Excellent prospects for improvement in capacity and EER by optimization compared to R-410 A across all temperature testing conditions for all categories and all refrigerants.

Chapter 4

4. Energy Efficiency and Progressive Changes in MEPS for Egypt

Egypt's MEPS (Minimum Energy Performance Standards) energy efficiency label requirement for mini split air conditioning units and window type, ES: 3795-/2013 and ES: 3795-/2016 Part 1-for constant speed compressors- define EER (BTU/W.hr) at T_1 condition (ISO 5151) across several efficiency classes, A 5+ to E as listed in the tables below according to regulation years, 2014 to 2021.

MEPS progression across the years:

The standards, starting June 2014, lists EER values for energy efficiencies that define a certain class, termed calibration level, starting from E to A^{++}, see table below.

Table 14: Egypt Energy Ratings per 2014 Standard

Calibration	Energy Efficiency ratio of a room air conditioner (Split AC)	
	Watt/ Watt	**B.T.U/ Watt/h**
A^{++}	Higher or equal to 4,1	Higher or equal to 14
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12
C	Higher than or equal to 3, 08 and less than 3, 22	Higher or equal to 10, 5 and less than 11
D	Higher than or equal to 2, 93 and less than 3, 08	Higher or equal to 10 and less than 10, 5
E	Higher than or equal to 2, 78 and less than 2, 93	Higher or equal to 9, 5 and less than 10

Those EER classes' changes to become progressively stricter, as of June 2017, see table shown below, new class created **A^{+++}** and class **E** removed:

Table 15: Egypt Energy Ratings per 2017 Standard

Calibration	Energy Efficiency ratio of a room air conditioner (Split AC)	
	Watt/ Watt	**B.T.U/ Watt/h**
A^{+++}	Higher or equal to 4,4	Higher or equal to 15
A^{++}	Higher than or equal to 4,1 and less than 4,4	Higher or equal to 14 and less than 15
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12
C	Higher than or equal to 3, 08 and less than 3, 22	Higher or equal to 10, 5 and less than 11
D	Higher than or equal to 2, 93 and less than 3, 08	Higher or equal to 10 and less than 10, 5

And in June 2019 as shown below, new class created **A⁺⁺⁺⁺** and class D removed:

Table 16: Egypt Energy Ratings per 2019 Standards

Calibration	**Energy Efficiency ratio of a room air conditioner (Split AC)**	
	Watt/ Watt	**B.T.U/ Watt/h**
A^{++++}	Higher or equal to 4,69	Higher or equal to 16
A^{+++}	Higher or equal to 4,4 and less than 4,69	Higher or equal to 15 and less than 16
A^{++}	Higher than or equal to 4,1 and less than 4,4	Higher or equal to 14 and less than 15
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12
C	Higher than or equal to 3, 08 and less than 3, 22	Higher or equal to 10, 5 and less than 11

Finally in June 2021 it becomes as shown below, new class created **A^{+++++}** and class **C** removed:

Table 17: Egypt Energy ratings per 2021 Standard

Calibration	**Energy Efficiency ratio of a room air conditioner (Split AC)**	
	Watt/ Watt	**B.T.U/ Watt/h**
A^{+++++}	Higher or equal to 4,98	Higher or equal to 17
A^{++++}	Higher or equal to 4,69 and less than 4, 98	Higher or equal to 16 and less than 17
A^{+++}	Higher or equal to 4,4 and less than 4,69	Higher or equal to 15 and less than 16
A^{++}	Higher than or equal to 4,1 and less than 4,4	Higher or equal to 14 and less than 15
A+	Higher than or equal to 3, 81 and less than 4,1	Higher or equal to 13 and less than 14
A	Higher than or equal to 3, 51 and less than 3, 81	Higher or equal to 12 and less than 13
B	Higher than or equal to 3, 22 and less than 3, 51	Higher or equal to 11 and less than 12

When the EER values are tabulated according to efficiency class (calibration) versus the year(s) when standards come into operation, the below table is obtained, where the most efficient class for each year(s) is in red followed by green, violet, sky blue, orange, light blue and navy blue as the class of efficiency becomes less and less . For all years there are 7 classes of efficiency.

The highest EER in 2014-2016 was 14 for class A^{2+} while in 2021 the highest EER will be 17 and a new classis created; A^{5+}. This continuous progression to more efficient systems is reflected in the graph below, where EERs are plotted across all years from 2014 to 2021. The top line denotes the highest EER for each regulation year, while the other lines are in descending order. The colors of the rows in the table correspond to the colors of the lines in the graph, 7 classes of efficiency for each year(s).

Table 18: EER Values at T1 according to the Egyptian Standard ES: 3795/2016

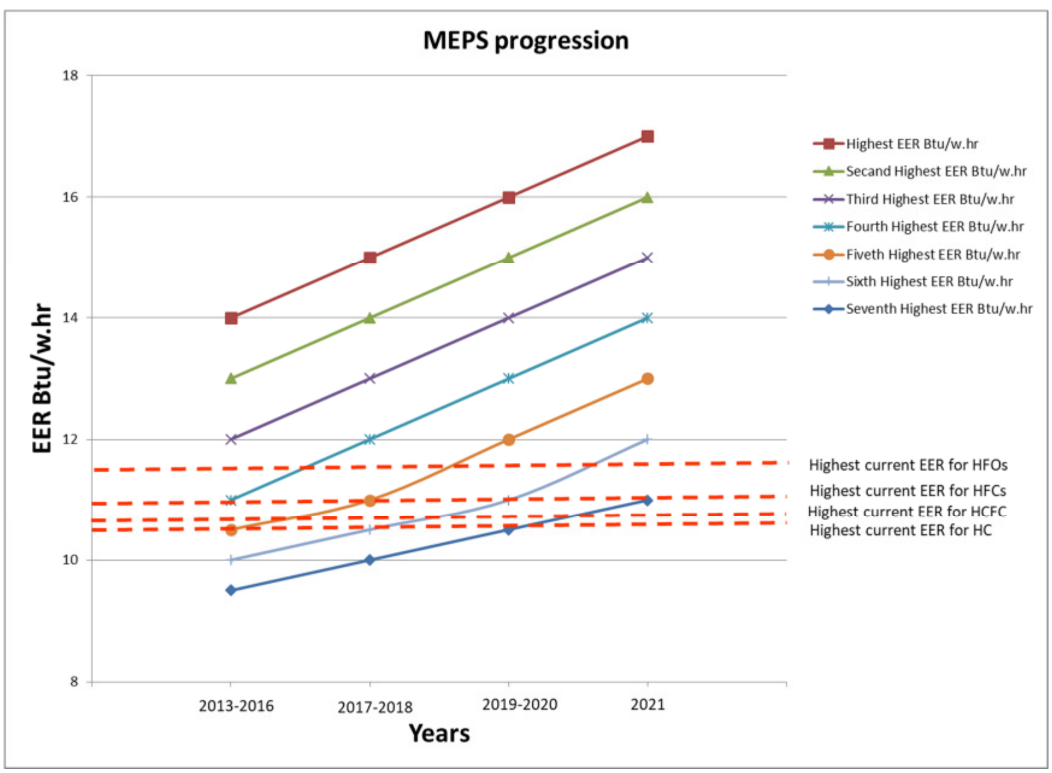
Eff. class /yr.	2014-2016	2017-2018	2019-2020	2021
A^{5+}				17
A^{4+}			16	16
A^{3+}		15	15	15
A^{2+}	14	14	14	14
A^{+}	13	13	13	13
A	12	12	12	12
B	11	11	11	11
C	10.5	10.5	10.5	
D	10	10		
E	9.5			

The table shows how the energy efficiency classes are increasing progressively with the years.

EER versus years:

The graph below shows the highest to lowest EER plotted against the years it came/coming into effect. The graph shows the progression to higher EER with the years. The values are taken from the table above. Seven classes are represented for each year.

Figure 14: EER curves for the highest in each class plotted vs. the standard regulation year



When the results of the Egyptian program for testing alternative low-GWP refrigerants for the Egyptian air conditioning industry, EGYPRA, are plotted on the graph as straight lines showing the best EER achieved for HCFCs, HFCs, HC and HFO, the following is shown:

- The highest EER of prototypes using HC-290 refrigerant is 10.35
- The highest EER of tested units using HCFC refrigerant is 10.5
- The highest EER of tested units using HFC refrigerant is 10.88
- The highest EER of prototypes using HFO refrigerant is 11.5

EGYPRA prototypes, especially made for the program, were optimized by choosing an optimum refrigerant charge and suitable selection of capillary tube (expansion device). No changes were made to either evaporator or condenser.

The best EER of alterative refrigerants cannot achieve at current optimization more than class B (light blue) for MEPS 2019-2020 and class B (navy blue) for 2021.

However, there is potential for improvement. The potential for improvement is based on the fact that the prototypes were built with many constraints (size and type of heat exchangers, size if the units, etc…). In future further optimization through the selection of compressors better suited to alternative refrigerants and the selection of heat exchangers that can improve the efficiency of the units will increase EER of the systems.

Can EER improvement be made from the current 11.5 to 16 in 2019 and 17 in 2 years? This remains to be seen, although it is unlikely. How far can EERs improve is related to the optimization process itself which requires research and development capabilities and capital cost and time. This might be beyond the capability of the majority of the manufacturers.

Further results of this correlation is as follows:

- Shifting to variable speed split units is inevitable if the higher efficiency EER standards are to be achieved by 2019 and beyond, with the resultant additional incremental costs associated with this shift, in manufacturing equipment and end product cost (USD 50 to 100).
- The introduction of Not-In-Kind cooling technology must be accelerated, if energy efficiency rates are to be improved for the air conditioning sector.

Chapter 5

5. Conclusion

EGYPRA is funded from Egypt's HCFC Phase-out Management Plan (HPMP) as an enabling activity for the benefit of the Egyptian air conditioning industry to help local manufacturers experiment working with new alternative lower-GWP refrigerants.

EGYPRA tested refrigerants with medium pressure characteristics similar to HCFC-22 and others with high pressure similar to R-410A in split system units. Testing of central units with higher capacity was not finalized in time for this report due to lack of testing facilities for flammable refrigerants at those capacities. Results will be reported in the future once testing and evaluation is done.

This conclusion is in two parts: technical and institutional regarding capacity building requirements.

5.1. Technical Conclusion

EGYPRA results lead to the following conclusions:

- As expected, and for all refrigerants, moving from T_1 to T_3 testing temperatures, both capacity and EER deteriorate, at different levels, across all categories and refrigerants;
- At T_{High}, the increased indoor wet bulb testing condition, as per EOS & ISO-5151, leads to better results for EER and capacity compared to T_3;
- Since $T_{Extreme}$ testing condition is similar to T_{High}, with regard to indoor wet bulb testing condition, both EER and capacity re-deteriorate;
- In general, there are candidates with potential for improvement; however, since high pressure refrigerants show better results vs. R-410A, the potential for improvement is higher.

Almost all of the OEMs who have participated in EGYPRA have already introduced R-410A units into the market. One uncorroborated study shows that more than 10% of the units sold in 2017 were with R-410A. This might make it easier for OEMs to leap-frog solutions for HCFC-22 and pass directly to high pressure alternatives to R-410A as the possibility for performance and EER improvement is higher for those alternatives.

Results also show that the potential for improvement applies also at higher ambient temperatures, an important factor for some of the regions in the south of Egypt that experience higher ambient temperatures than 35 °C. This is also important for the export market as some manufacturers export to neighboring HAT countries in the region.

5.2. Capacity Building Requirements

The conclusion from chapter 4 is clear: at the current optimization level, none of the prototypes tested will be able to meet more than class B of the 2021 MEPS values; however, the fact is that prototypes were built with many constraints

- The prototypes could be further optimized through the selection of compressors better suited to the tested refrigerants and the selection of heat exchangers that can improve the efficiency of the units;
- Variable speed technology would improve the Seasonal EER of the units where applicable;
- The optimization process requires research and development capabilities that might go beyond those available at some of the manufacturers;

- A further conclusion concerns the testing facilities of the EGYPRA OEMs. Witness testing has enabled the Technical Consultant to carefully assess the capabilities of each lab, especially for testing flammable refrigerants. For confidentiality purposes, the general description of the lab facilities given in Annex 2 does not aim to critique the individual labs or divulge where the individual labs need to be upgraded; however, the fact remains that some of the labs could benefit from an upgrade program;
- The lack of an accredited independent lab to test larger than 65,000 Btuh units using flammable refrigerants was the reason for the delay in testing central units which are part of the EGYPRA project. These units were built by the respective manufacturers; however, the arrangement for testing them independently and with good certainty could not be made on time for this report.
- Test results show that all refrigerants used in the project are viable alternatives from a thermodynamic point of view. The viability in terms of the other criteria like commercial availability, cost, and safety – among others - needs to be further researched.

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Annex 1: Test Results

The annex includes tables and charts from the test results. All OEMs results were compiled by category, for HCFC-22 equivalent refrigerants and for R-410A equivalent refrigerants.

The tables show the results for capacity in Btuh and EER at the four testing temperatures. The tables are per category of 12,000 Btuh split units, 18,000 split units and 24,000 Btuh split units. They include all alternatives refrigerant tested by each OEM.

The equivalent bar charts reflect the results in the tables: one bar chart for capacity and one bar chart for EER.

The sequence in which they are presented is:

- Table and bar chart equivalents for HCFC-22 alternatives in the 12,000 Btuh category;
- Table and bar chart equivalents for HCFC-22 alternatives in the 18,000 Btuh category;
- Table and bar chart equivalents for HCFC-22 alternatives in the 24,000 Btuh category;
- Table and bar chart equivalents for R-410A alternatives in the 12,000 Btuh category;
- Table and bar chart equivalents for R-410A alternatives in the 18,000 Btuh category;
- Table and bar chart equivalents for R-410A alternatives in the 24,000 Btuh category.

Table 19 A1: Capacity and EER Results for HCFC-22 alternatives in 12,000 Btuh category

HCFC-22 eq. 12,000 Btuh		OEM A				OEM B				OEM C				OEM E			
Ambient		T_1	T_3	T_{high}	T_{Ext}	T_1	T_3	T_{high}	T_{Ext}	T_1	T_3	T_{high}	T_{Ext}	T_1	T_3	T_{high}	T_{Ext}
R-22	CAP	11479	9699	11353	8407	11410	9988	10900	10035	11452	9960	10560	10181	10753	10415	10352	9381
	EER	9.74	6.88	7.31	5.61	8.410	6.380	6.330	5.470	10.002	7.249	6.975	6.231	10.290	8.300	7.380	6.230
R-290	CAP									10219	8677	9289	7747				
	EER									10.355	7.171	6.959	5.217				
ARM-20a R-457A	CAP									11023	9376	10892	9517				
	EER									8.358	6.239	6.582	5.556				
Opteon XL-20 R-454C	CAP					10968	9349	9946	9042					6980.6	4958.27	5762.15	4489.25
	EER					7.970	6.000	5.860	5.050					8.150	5.200	5.600	4.180
L-20 R-444B	CAP	11790	9661	10241	8881												
	EER	8.43	5.73	5.53	4.47												

Figure 15 A1 - Equivalent capacity charts for HCFC-22 alternatives in 12,000 Btuh category plotted vs HCFC-22 results

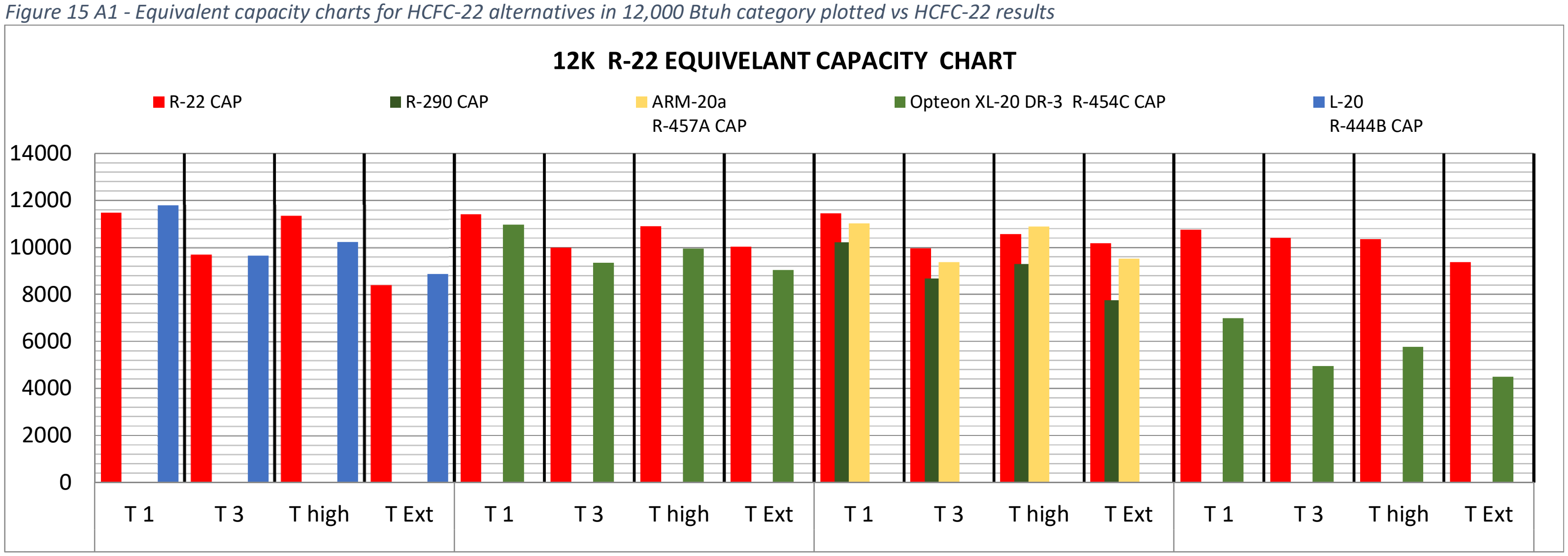


Figure 16 A1 - Equivalent EER chart for HCFC-22 alternatives in 12,000 Btuh category plotted vs HCFC-22 results

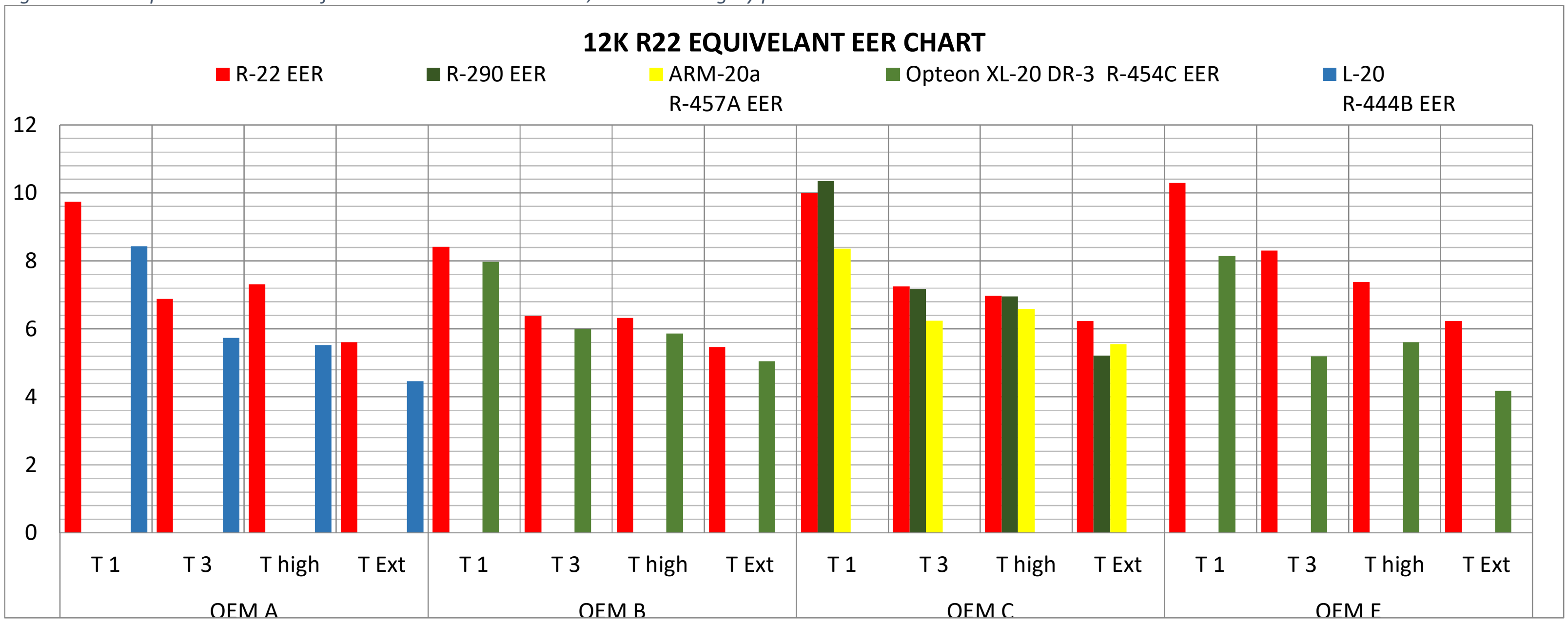


Table 20 A1- Capacity and EER results for HCFC-22 alternatives in 18,000 Btuh category

HCF-22 eq. 18,000 Btuh		OEM A				OEM B				OEM C				OEM D			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**
R-22	CAP	18659	16799	17543	15046	16433	14545	13718	15350	18160	16182	17632	16292	17548	16422	14624	13948
	EER	9.410	7.260	6.980	5.550	8.930	6.650	6.370	5.330	10	7.372	7.371	6.445	10.500	8.750	7.220	6.00
R-290	CAP	16111	14067	15343	13442												
	EER	9.310	7.090	7.170	5.860												
R-457A	CAP					15257	12672	13418	12149								
	EER					9.260	6.590	6.310	5.330								
R-454C	CAP									16510	14327	15619	14250				
	EER									9.312	6.972	7.011	6.015				
R-444B	CAP													17098	15746	13498	13047
	EER													10.000	7.780	6.320	5.400

Figure 17 A1 - Equivalent capacity charts for HCFC-22 alternatives in 18,000 Btuh category plotted vs HCFC-22 results

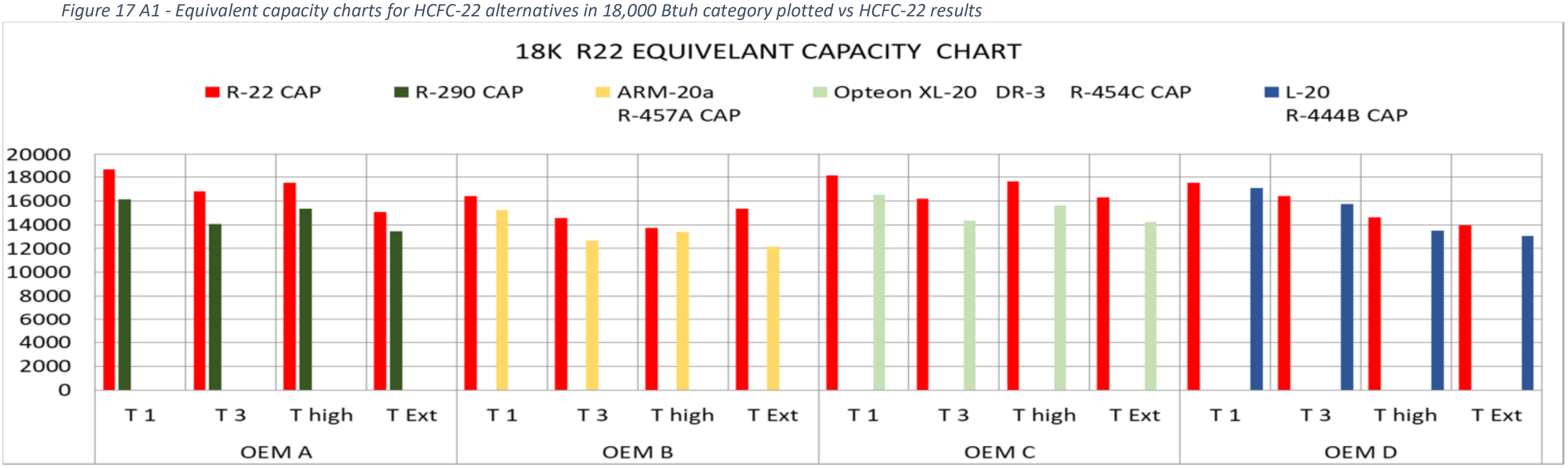


Figure 187 A1 - Equivalent EER charts for HCFC-22 alternatives in 18,000 Btuh category plotted vs HCFC-22 results

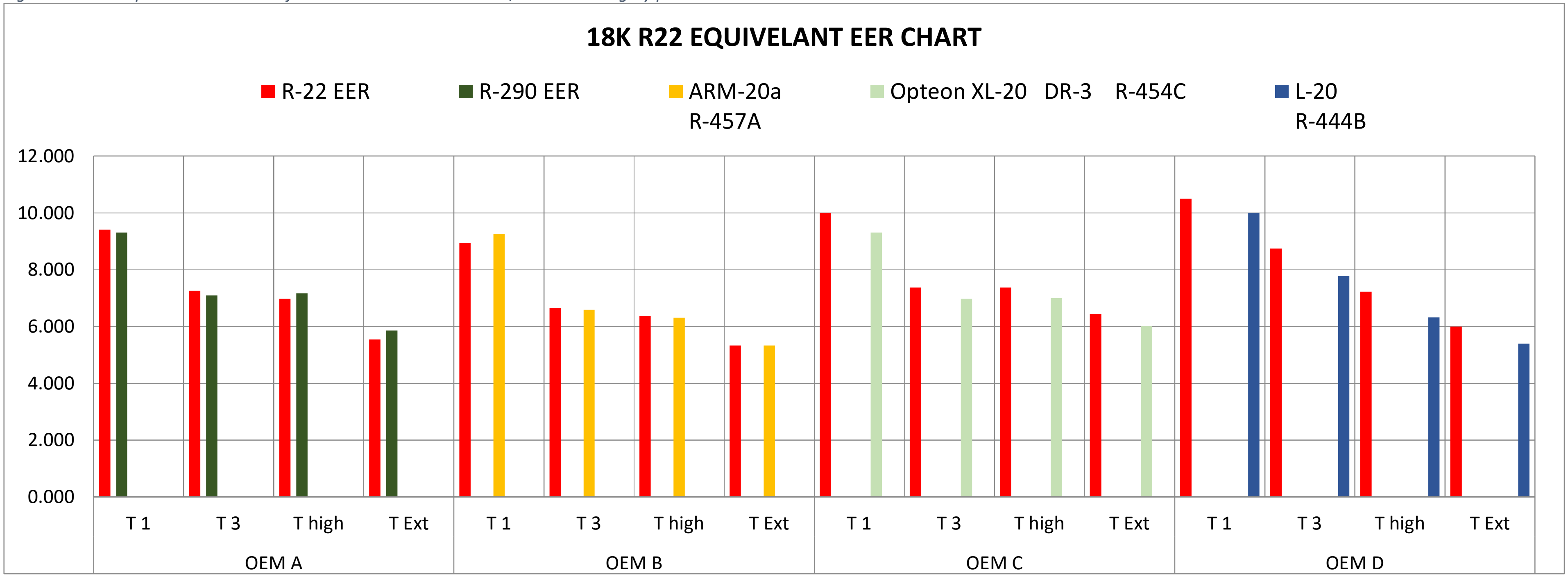


Table 21 A1 - Capacity and EER results for HCFC-22 alternatives in 24,000 Btuh category

HCFC-22 eq. 24,000 Btuh		OEM B				OEM D			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**
R-22	CAP	22782				22318	21202	20144	19148
	EER	9.270				9.300	7.320	6.100	5.73
R-290	CAP								
	EER								
ARM-20a R-457A	CAP					21758	20670	19636	18657
	EER					8.78	6.85	5.82	5.25
Opteon XL-20 DR-3 R-454C	CAP								
	EER								
L-20 R-444B	CAP	23436							
	EER	7.38							

Figure 19 A1 - Equivalent capacity charts for HCFC-22 alternatives in 24,000 Btuh category plotted vs HCFC-22 results

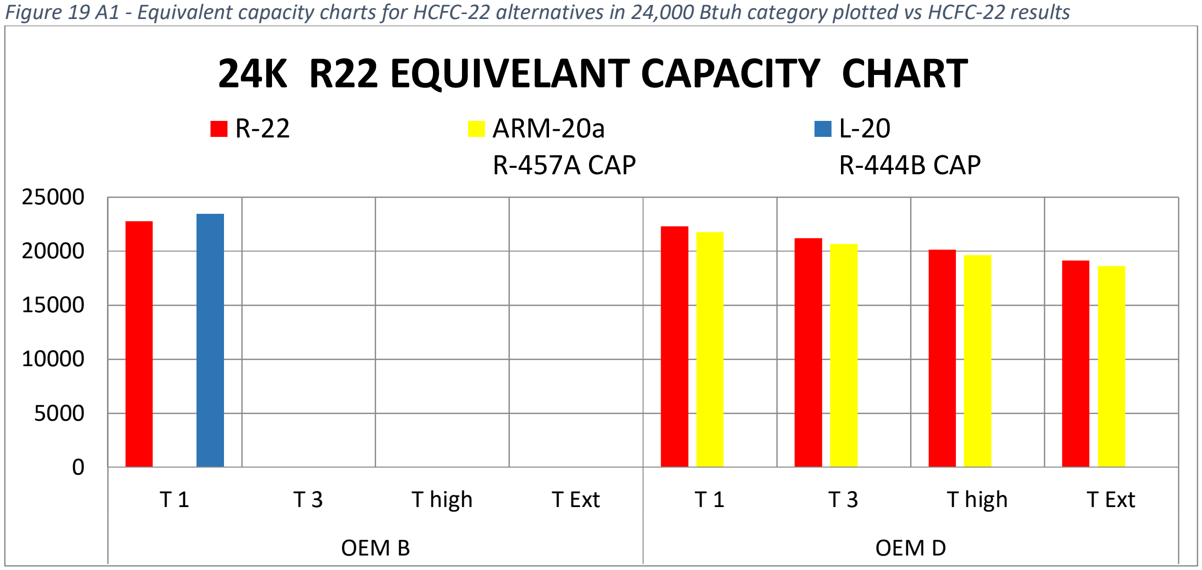


Figure 20 A1 - Equivalent EER chart for HCFC-22 alternatives in 24,000 Btuh category plotted vs HCFC-22 results

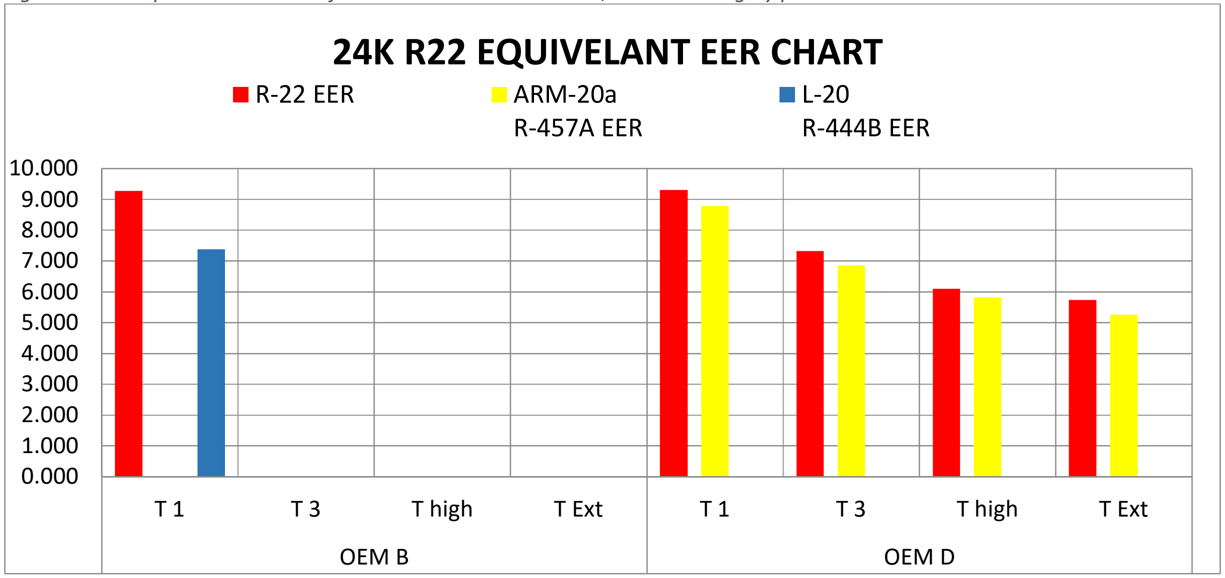


Table 22 A1 - Capacity & EER results for R-410A alternatives in 12,000 Btuh category

R-410 A eq.		OEM A				OEM B				OEM E			
12,000 Btuh Ambient		**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**
R-410A	CAP	10307	-	8313	-	12068	10343	11089	9968	11905	9369	10848	9299
	EER	8.77	-	5.43	-	10.17	7.31	7.15	5.93	10.88	7.29	7.42	5.89
ARM-71a R-459A	CAP												
	EER												
R-32	CAP					11355	9249	9822	8499				
	EER					11.51	7.53	7.26	5.69				
Opteon XL-41 DR-5 R-454B	CAP									11987	11130	12257	11094
	EER									9.92	7.95	7.66252	6.7676
L-41 R447A	CAP	9963	-	8539	-								
	EER	8.38	-	5.55	-								

Figure 21 A1 - Equivalent capacity chart for R410A alternatives in 12,000 Btuh category plotted vs R-410A results

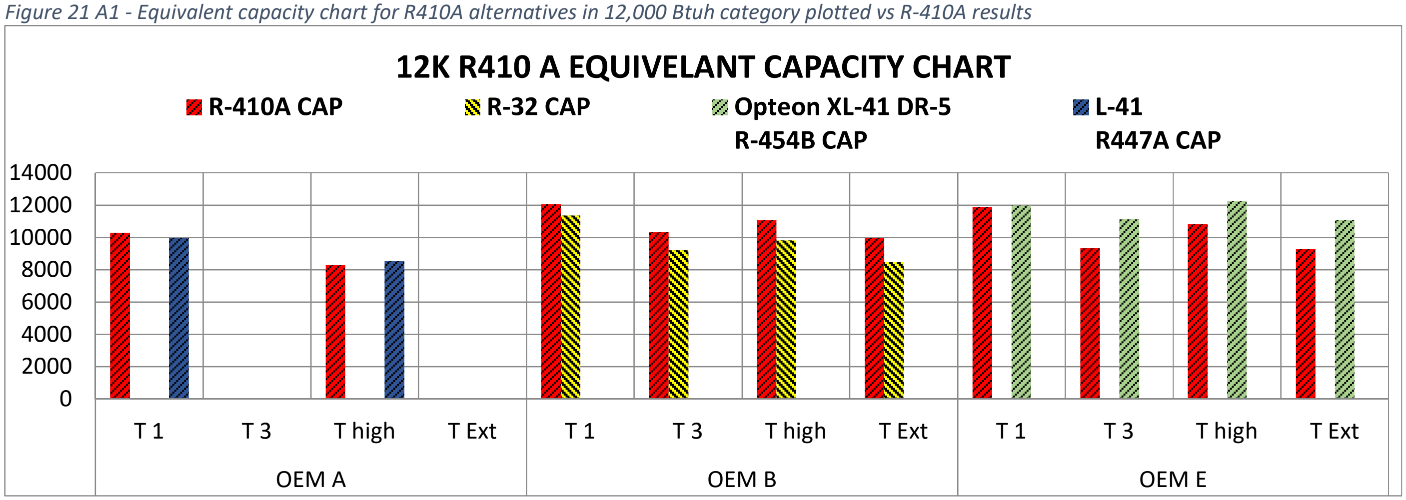


Figure 22 A1 - Equivalent EER chart for R-410A alternatives in 12,000 Btuh category plotted vs R-410A results

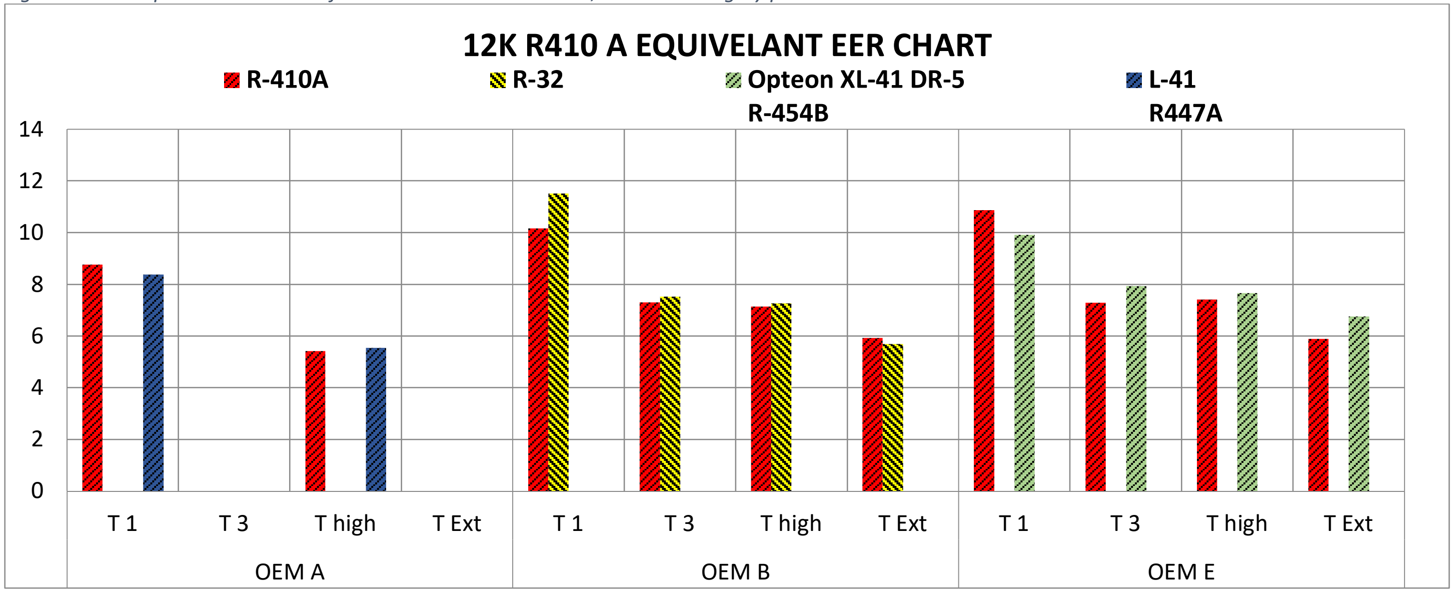


Table 23 A1 - Capacity & EER results for R-410A alternatives in 18,000 Btuh category

R-410 A eq. 18,000 Btuh		OEM A				OEM C			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**	**T 1**	**T 3**	**T high**	**T Ext**
R-410A	CAP	16938	14337	14123	12441	17800	14924	16075	13746
	EER	9.8	6.8	6.3	5.1	9.152	6.497	6.485	5.116
ARM-71a R-459A	CAP					17115	14430	15392	14023
	EER					9.282	6.544	6.265	5.32
R-32	CAP	17616	15255	15761	13809				
	EER	10.03	7.1	6.65	5.29				
Opteon XL-41 DR-5 R-454B	CAP	15167	13229	13782	11800				
	EER	9.5	6.9	6.5	5.2				
L-41 R447A	CAP								
	EER								

Figure 23 A1- Equivalent capacity charts for R-410A alternatives in 18,000 Btuh category plotted vs R-410A results

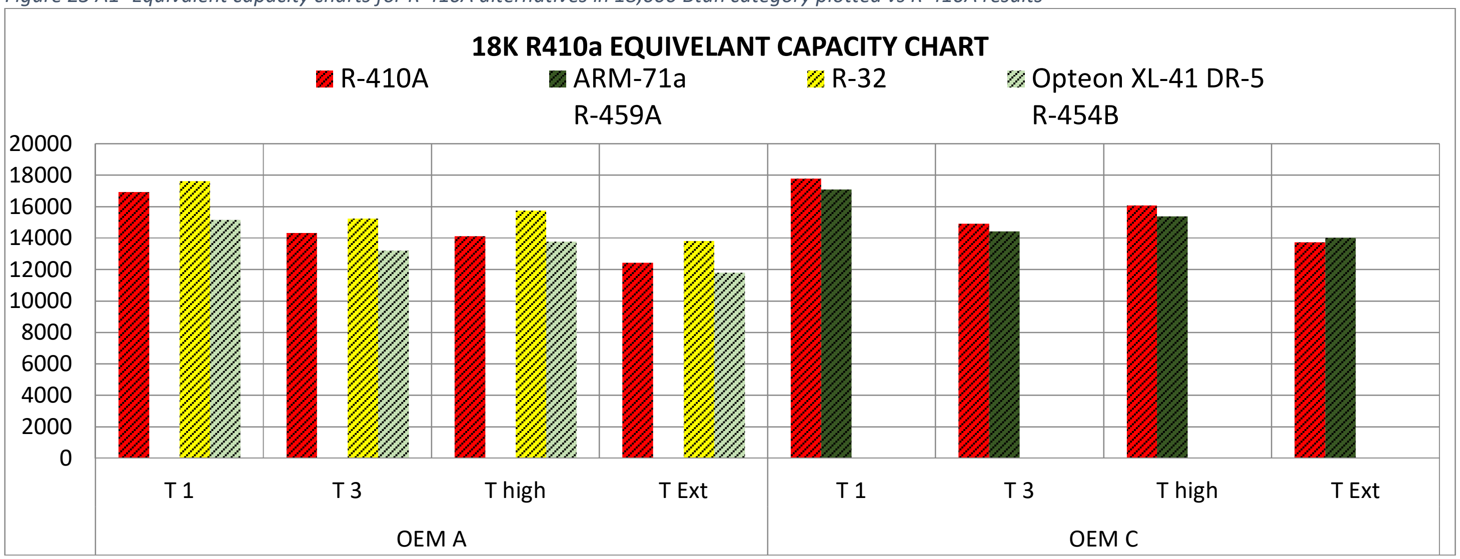


Figure 24 A1 - Equivalent EER chart for R-410A alternatives in 18,000 Btuh category plotted vs R-410A results

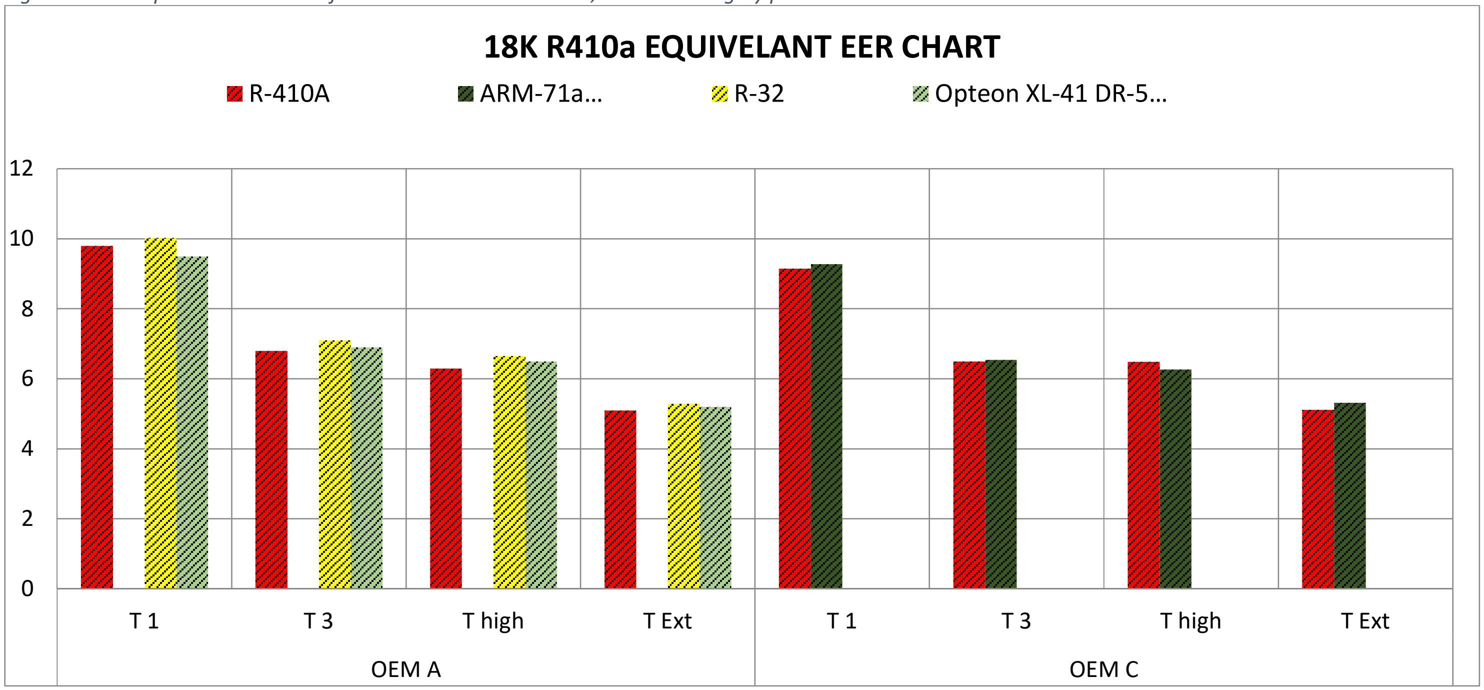


Table 24 A1 - Capacity & EER results for R-410A alternatives in 24,000 Btuh category

R-410 A eq. 24,000 Btuh		OEM C			
Ambient		**T 1**	**T 3**	**T high**	**T Ext**
R-410A	CAP	23022	19531	20534	18379
	EER	10.57	7.518	7.376	6.161
ARM-71a R-459A	CAP				
	EER				
R-32	CAP	23310	19522	21876	19035
	EER	10.62	7.228	7.459	5.988
Opteon XL-41 DR-5 R-454B	CAP	23766	20241	22268	20160
	EER	10.653	7.516	7.515	6.224
L-41 R447A	CAP				
	EER				

Figure 25 A1 - Equivalent capacity charts for R-410A alternatives in 24,000 Btuh category plotted vs R-410A results

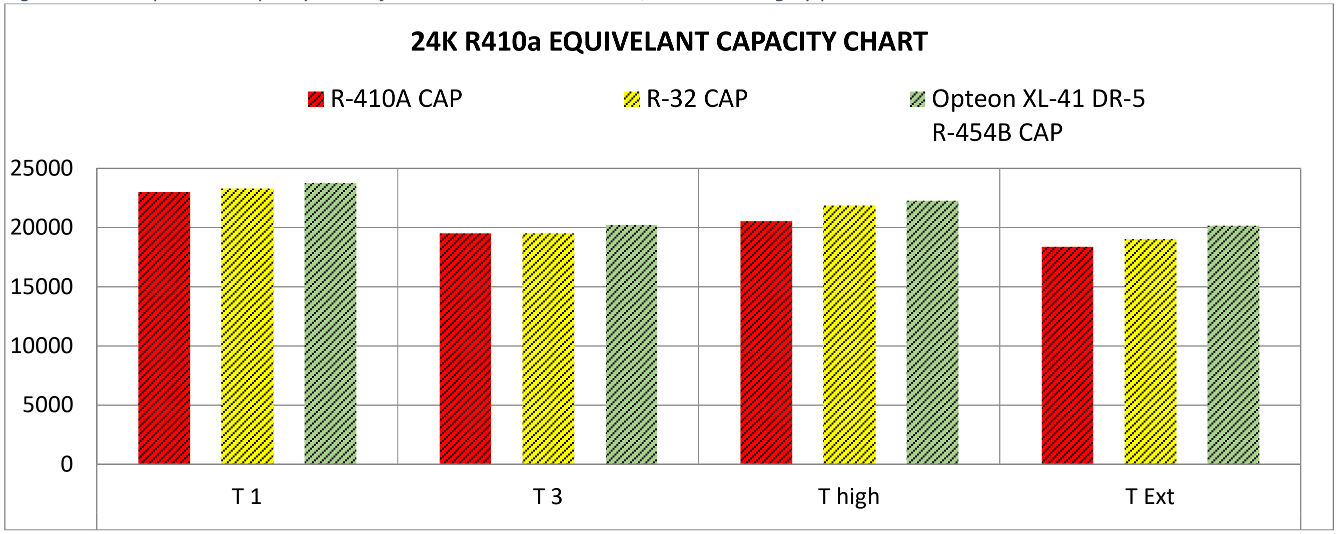
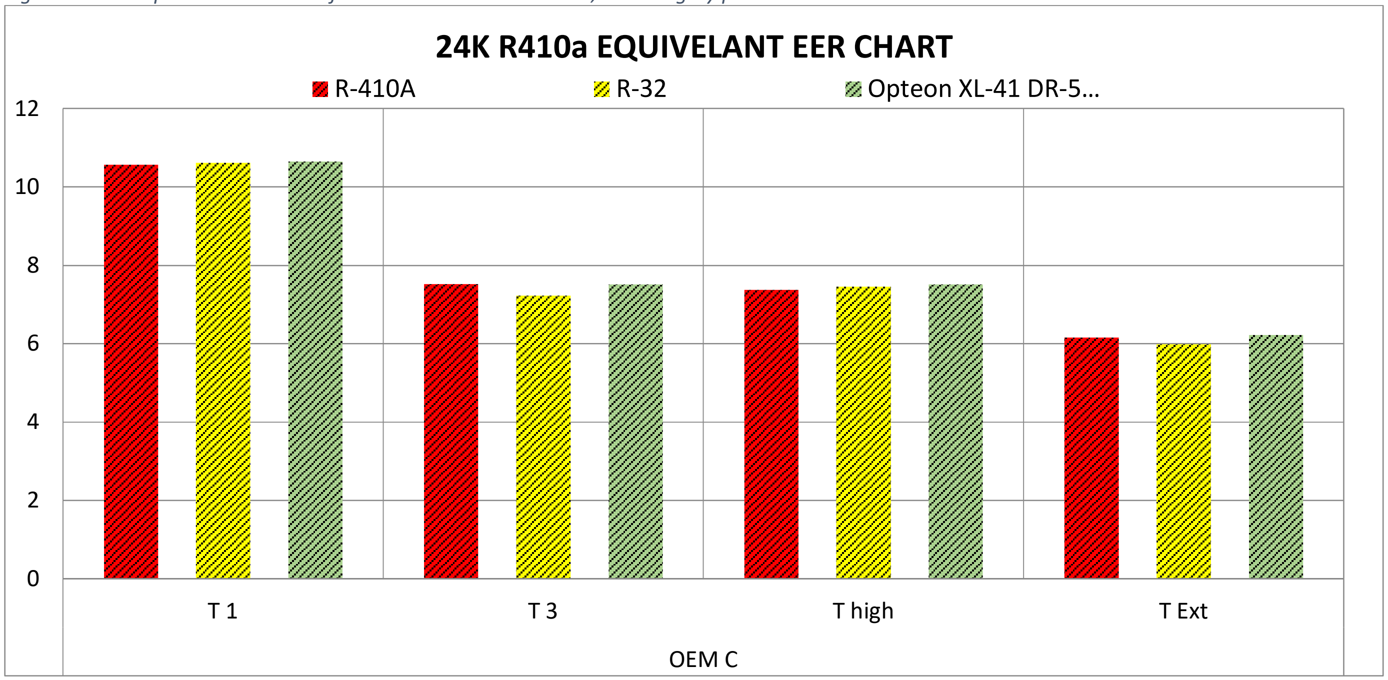


Figure 26 A1 - Equivalent EER chart for R-410A alternatives in 24,000 category plotted vs R-410A results



Annex 2: Sample Questionnaire for Local Manufacturers

Goal:

The Initiative objective is to test prototype air-conditioning units using low-GWP alternative technologies and share recommendations with manufacturers and decision makers in Egypt

Questionnaire:

This questionnaire is aimed at selected air-conditioning manufacturers in Egypt. The purpose of the questionnaire is to ask the preferences of the selected manufacturers in as far as technology selection and partnership with other stakeholders as well as getting a confirmation on their willingness to participate. All information complied of this questionnaire will be treated as confidential.

A. General Conditions	**Participant response**
My company is willing to participate in the project. If you answer YES, please proceed to rest to questionnaire.	YES NO

B. Technology Selection	**Participant response**
1. Do you have a preference for the alternative refrigerant?	YES NO
2. Alternative refrigerant choice (*you can provide more than one selection by deleting what is not applicable)*	➢ HFO Honeywell ➢ HFO DuPont ➢ R-32 ➢ Hydrocarbon
3. Do you have a preference for the compressor manufacturer?	YES NO
4. Provide name of compressor manufacturer(s)	

C. Application Selection	**Participant response**
5. Do you have a preference for the type and capacity of equipment for which you will build the prototype?	YES NO
6. My selection of equipment: (*you can provide more than one selection)*	➢ Decorative split ➢ Ducted split ➢ Rooftop package ➢ Self-contained
7. My selection of cooling capacity	➢ 1 – 5 tons ➢ 6 – 10 tons ➢ No preference

D. Building Prototypes	**Participant response**
8. My company can design and/or build prototypes	YES NO
9. How many prototypes are you willing to build?	➢ One ➢ More (*pls specify number)*

E. Testing Prototypes	**Participant response**
10. Which type of testing do you prefer?	➢ Independent 3rd party Testing ➢ Witness Testing at own premises
11. If you answered **3rd Party Testing**, are you willing to pay the cost for the test?	YES NO

12. If you answered **Witness Testing**, is your lab certified and by whom?	YES NO Certified by:

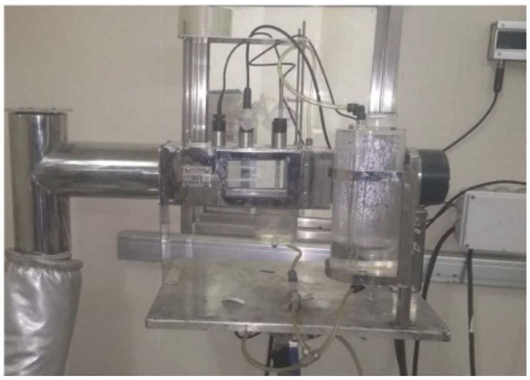
F. Logistics	Participant response
13. My company will allow independent consultants appointed by UNEP/UNIDO to oversee the development of the prototypes.	YES NO
14. If NO, pls describe what limitations you want to impose.	
15. My company will allow independent consultants appointed by UNEP/UNIDO to oversee the testing of the prototypes.	YES NO
16. If NO, pls describe what limitations you want to impose.	

G. Information about the Company	Participant response
17. Company Name	
18. Brand names used in market	
19. Company headquarters location	
20. Manufacturing location where prototype will be built	
21. Ownership percentage pertaining to the nationality where prototype is manufactured (*This information is needed to determine whether the limitations for project participation set by the Ozone Secretariat of the Montreal Protocol are applicable)*	
22. Name and title and Contact details of designated contact person for this project	

Annex 3: Brief description of Manufacturers' testing labs

The test labs of the different OEMs had varying capabilities. The best equipped labs have the following characteristics:

- Psychrometric type laboratory in which the air enthalpy test method is used to determine the cooling and heating capacities from measurements of entering and leaving wet-and dry-bulb temperatures and the associated airflow rate;
- Air sampling devices in each room (indoor room, code tester and outdoor room) are used to measure an average temperature. The airflow induced using blower through the tree (photo on left) and insulated duct passing over the temperature instruments (photo on the right) at velocity of 4-5 m/s.



- Air flow measuring apparatus (code tester) is attached to air discharge of UUT by insulated duct. The first section (receiving chamber) delivers air from UUT and contains the static pressure measuring instrument. The air is then mixed by a mixer in next section to measure its temperature by the air sampling device installed inside the code tester.

- Nozzles section, consisting of a receiving chamber and a discharge chamber separated by a partition in which four nozzles are located (see photo below). Air passes through the nozzles and is then exhausted to the test room. The pressure drop across the nozzles is measured using differential pressure transmitter. Air flow rate is calculated according to ISO 5151:2017.

- Voltage stabilizer(photo on left) is used to adjust the applied voltage for UUT, and the Power meter device is used to measure electrical parameters for it like applied voltage, power consumption, current consumption and power factor.

- Most labs are capable of testing up to 5 TR capacity (17.5 kW of cooling) measuring unit working pressure, super-heat, sub-cooling, and various temperature points on the refrigeration cycle;
- Lab consists of two well thermally insulated rooms: indoor room and outdoor room. In both rooms, temperature and humidity can be controlled preciously to achieve the required environment, as per different standards, thru refrigeration units, humidifiers and electric heaters;
- The accuracy of temperature control for dry and wet bulb temperature is 0.01 °C;
- In the indoor room there is a thermal insulated code tester where outlet air dry bulb, wet bulb and volume are measured;
- Wires sensors with accuracy of 0.1 °C are used for measuring surface temperatures at various points;
- Information gathered during the test are monitored on a computer screen;

The table below shows the parameters that are shown on the monitor

Table 25 A3: Typical parameters shown on a testing lab monitoring screen

Test Screen Display
Inlet DB
Inlet WB
Inlet Enthalpy
Outlet DB
Outlet WB
Outlet Enthalpy
Enthalpy Differential
Specific Density
Air velocity
Air volume
Standard air volume
Atmospheric pressure
Differential pressure
Heat Loss
Total capacity
Capacity ratio
EER
EER ratio
COMPRESSOR
FM surface temperature
high pressure
low pressure
Super-heat
Sub-cooling
ADDITIVE TEMP.
Accumulator outlet temp
Outlet air temperature
Evaporator coil sensor temp
Compressor inlet
O/D Motor surface
OUTDOOR UNIT
Inlet DB
Inlet WB
POWER
Voltage
Current
Wattage
Power Factor
Frequency

Annex 4: Other Research Programs

Research at High Ambient Temperature

The dedicated research on the performance of refrigerants at High Ambient Temperatures (HAT) was driven by the need to find low-GWP alternative refrigerants that have a better degradation of capacity and efficiency than the commercial HFCs that are replacing HCFCs in the HAT countries. The need to meet higher Minimum Efficiency Performance Standards (MEPS) while phasing out the current production of HCFC-based units was a challenge facing both the local industry in the HAT countries and the global exporters to those markets.

Three research programs were announced and completed in the time period between 2013 and 2016. While the three programs had a common goal in testing the refrigerant alternatives at temperatures higher than the standard T1 testing conditions, they were distinct in their protocols, approach, and the entity who was behind the project.

The PRAHA program mentioned in Chapter 1 is a Multilateral Fund financed project to test custom-built prototypes in four equipment categories that built by manufacturers located in HAT countries and testing them all at one independent lab. The results were compared to base units running with HCFC-22 and R-410A refrigerants.

The AREP (Alternative Refrigerant Evaluation Program) is an industry association program by the Air Conditioning, Heating, and Refrigeration Institute (AHRI) to test various categories of equipment, by various manufacturers, at their own labs by either dropping in the refrigerant or "soft" optimizing the unit.

The Oak Ridge National Laboratory (ORNL) program by the United States Department of Energy (DoE) tested two similar capacity standard units running with HCFC-22 and R-410A and soft optimizing them for the various alternative refrigerants. All tests were carried on at ORNL labs.

A comparison of the three program design criteria and testing protocols is found in table xx below. In the next sections of this chapter is a resume of the test results for the three programs and a comparison of these results.

PRAHA program

Six local Original Equipment Manufacturers (OEMs) built 14 prototypes running with five refrigerant alternatives and shipped 9 other "base units' operating with HCFC or HFC for direct comparison purposes. Testing was done at 35, 46, and 50 °C ambient temperatures with an "endurance" test at 55 °C ambient to ensure no tripping for two hours when units are run at that temperature. The indoor conditions will be kept the same for all tests; dry bulb temperature of 27 ^{o}C and a relative humidity of 50 % as per AHRI test procedures for T1 conditions (35 ^{o}C), and 29 ^{o}C and 50% for T3 (46 ^{o}C and 50 ^{o}C) conditions. A memorandum of understanding (MOU) was signed with AHRI (Air-Conditioning, Heating and Refrigerating Institute) for exchanging experience on the testing methodology benefiting of AHRI relevant research project known as AREP.

The project compares the following refrigerants: R-290, HFC-32, R-444B (herein referred to as L-20), R-447A (L-41), and DR-3 to HCFC-22 or R-410A. Prototypes operating with R-290, R-444B, and DR-3 are compared with HCFC-22 as they portray similar characteristics to HCFC-22, while HFC-32, and R-447A are compared with R-410A.

All the prototypes in every category were built to have the same cooling capacity and fit in the same box dimensions as their respective base units, and they were all required to meet the minimum energy efficiency (EER) of 7 at 46 °C. Tests were performed at an independent reputable lab for result consistency; Intertek was selected through competitive bidding. Verification for repeatability was performed to ensure that results are within the acceptable accuracy levels.

Table 26 A4 - Results for PRAHA-I program

Equipment type	Baseline refrigerant	Refrigerant tested	COP % comp to baseline @ 35°C	Capacity % comp to baseline @ 35°C	COP % comp to baseline @ 50°C	Capacity % comp to baseline @ 50°C
18,000 Btu/hr. Window Unit	HCFC-22 COP = 3.14 (35°C), 2.26 (50°C) for OEM A COP = 2.76 (35°C), 2.02 (50°C) for OEM B	L-20 (OEM A)	-11%	9%	-10%	7%
		L-20 (OEM B)	-2%	-6%	-5%	-10%
		DR-3 (OEM A)	-9%	2%	-2%	1%
24,000 Btu/hr. split system	HCFC-22 COP = 2.75 (35°C), 1.94 (50°C) for OEM C COP = 2.52 (35°C) for OEM D	HC-290 (OEM C)	4%	8%	-2%	5%
		L-20 (OEM D)	-19%	7%	-76%	-78%
		DR-3 (OEM D)	-27%	-33%	-28%	-31%
24,000 Btu/hr. split system	R-410A COP = 3.52 (35°C), 2.30 (50°C) for OEM E COP = 3.08 (35°C), 2.02 (50°C) for OEM F	HFC-32 (OEM E)	-1%	15%	-2%	16%
		HFC-32 (OEM F)	-9%	8%	-22%	-1%
		L-41 (OEM E)	-10%	20%	-7%	22%
36,000 Btu/hr. Ducted Split	HCFC-22 COP = 2.83 (35°C), 1.91 (50°C) for OEM G	L-20 (OEM G)	0%	-7%	2%	-5%
		DR-3 (OEM G)	-18%	-25%	-13%	-21%
36,000 Btu/hr. Ducted Split	R-410A COP = 2.79 (35°C), 1.84 (50°C) for OEM G	HFC-32 (OEM G)	-1%	-4%	-12%	-18%
90,000 Btu/hr. Rooftop	HCFC-22 COP = 2.95 (35°C), 2.07 (50°C) for OEM H	L-20 (OEM H)	1%	6%	-3%	5%
		DR-3 (OEM H)	-3%	-1%	-6%	-4%

AREP Program

The Alternative Refrigerant Evaluation Program (AREP) by the Air Conditioning, Heating, and Refrigeration Institute (AHRI) tested several refrigerants either as a drop-or in soft optimized units built and tested at various manufacturers who are members of AHRI (AREP 2014). Testing was done in two phases for several applications including refrigeration and at various temperatures.

Table 27 A4 - Results for the AREP program

Equipment type	Base-line refrigerant	Modifications (test-type)	Refrigerant tested	COP % compared to baseline @ 35 °C	Capacity % compared to baseline @ 35 °C	COP % compared to baseline @ 51.6 °C	Capacity % compared to baseline @ 51.6 °C
36,000 Bu/hr. Split heat pump. AREP report 52(6)	R-410A COP = 3.55 at 35C and 1.87 at 51.6C	Criteria: Drop-in. Matching superheat and sub cooling to base unit. Charge level determined by criteria and held constant for all temperatures tested.	ARM-71A	-1%	-8%	7%	-3%
			R-454A (DR-5A)	-1%	-6%	6%	-1%
			HPR2A	-4%	-11%	3%	-4%
			R-446A (L-41-1)	-2%	-10%	-1%	-3%
			R447A (L-41-2)	-1%	-7%	-1%	-4%
48,500 Btu/hr. Rooftop AREP report 56(11)	R-410A COP = 3.31 at 35C, 2.00 at 48.9C and 1.80 at 51.6C	Soft optimization. Adjustable expansion device, Variable Frequency drive matching the capacity with base unit. Varying indoor conditions.	DR-55	4%	0%	3%	0%
			HFC-32	6%	1%	NA	NA
			DR-5A	5%	1%	7%	3%
72,000 Btu/hr. Rooftop AREP report 55(10)	R-410A COP = 3.57 at 35 C and 2.06 at 51.6C	Soft Optimization. Same superheat and sub cooling as base, changing expansion devise and adjusting charge. Oil is also different.	HFC-32	2%	9%	10%	16%
34,000 Btu/hr. split AREP Report 42(5)	R-410A COP = 3.53 at 35C and 1.82 at 51.6C	Tested HFC-32 unit with POE oil and withy prototype oil for the same expansion devise and charge determined by superheat.	HFC-32 with prototype oil	3%	7%	13%	14%
60,000 Btu/hr. Rooftop AREP reports 47 & 53 (8, 9)	R-410A COP = 3.87 at 35C and 2.07 at 51.6C	Soft optimization. Matching superheat and sub cooling.	L-41-2	3%	-7%	10%	-1%
			ARM-71A	3%	-4%	10%	2%
			HPR2A	1%	-5%	8%	1%
			DR-5A	1%	-4%	2%	-3%
			HFC-32	-10%	-4%	-9%	-1%

ORNL Program

The Oak Ridge National Laboratory (ORNL) program consisted of testing alternatives of HCFC-22 and R-410A in two units of the same capacity (Abdelaziz 2015). Testing was done at the ORNL labs at various temperatures. Table below shows the criteria and a comparison of the result.

Table 28 A4 - Results for the ORNL program

Equipment Type	Lab utilized	Baseline Refrigerant	Equipment Criterion	Refriger. Tested	COP % comp to baseline @ 35°C	Capacity % comp to baseline @ 35°C	COP % comp to baseline @ 52°C	Capacity % comp to baseline @ 52°C
18,000 Btu/hr. Split unit (Carrier)	ORNL	HCFC-22 COP = 3.07 at 35°C and 1.98 at 52°C	Same machine to test all refrigerants. Criteria: matching superheat and sub cooling to base unit. Changing expansion devise. Charge level optimized at 35C	N-20B	-13%	-14%	-11%	-15%
				DR-3	-16%	-12%	-14%	-12%
				ARM-20B	-12%	-3%	-11%	-3%
				R-444B (L-20A)	-11%	-9%	-7%	-4%
				HC-290	7%	-8%	7%	-4%
18,000 Btu/hr. split unit (Carrier)	ORNL	R-410A COP = 3.4 at 35°C and 2.07 at 52°C	Same machine to test all refrigerants. Criteria: matching superheat and sub cooling to base unit. Changing expansion devise. Charge level optimized at 35C	HFC-32	4%	5%	5%	11%
				DR-55	3%	-3%	3%	0%
				R-447A (L-41)	-5%	-14%	3%	-6%
				ARM-71a	-1%	-8%	2%	-4%
				HPR-2A	-2%	-9%	5%	-1%